AEC Category: HEALTH AND SAFETY

CEX-58.1

CIVIL EFFECTS EXERCISE

EXPERIMENTAL EVALUATION OF THE RADIATION PROTECTION AFFORDED BY RESIDENTIAL STRUCTURES AGAINST DISTRIBUTED SOURCES

J. A. Auxier, J. O. Buchanan,
C. Eisenhauer, and H. E. Menker

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CIVIL EFFECTS TEST OPERATIONS

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September 1958

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ABSTRACT

A study was made to obtain information that could be used to evaluate the protection afforded by residences against radiation due to fallout. The sources used were Co^{60} and Cs^{137}, and the radiation dosimeters used were pocket type ionization chambers. Measurements were made for distributed sources (400 Co^{60} and 20 Cs^{137}) and for single sources located inside the structures (one each, 2-curie Co^{60} and Cs^{137}).

Attenuation measurements were made for five houses of typical domestic design and construction. Several modifications were made to the houses, and the attenuation measurements were repeated. The houses, located at the Nevada Test Site, included single- and two-story houses with and without basements and with light and heavy walls. For comparison with the house data the dose-rate distribution above an extended plane source was measured in a "phantom" house, i.e., air measurements with the instrument fixed on a framework of thin-walled aluminum tubing. Although the complete analysis of the data is not yet available, some typical analyses are presented, and the effectiveness of some of the modifications is illustrated.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the several participants whose boundless efforts brought the experiment to fruition. Also, the authors gratefully acknowledge the many valuable contributions made to the project by each of the following:

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

There has been a need for specific experimental data concerning the protection afforded occupants of typical homes against radiation from fallout which could result from any enemy attack. Previous work in this field has been limited largely to theoretical calculation of protection factors for simple geometric configurations.[1–8] Some work has been done in Great Britain and Canada with distributed sources but on residences not necessarily typical of those in the United States.[9–11] Because of the urgent need for better data, the present project was established.

To minimize the precautions necessary to protect personnel not connected with the program and to make optimum use of the time available, it was decided to utilize certain of the residential structures constructed at the Nevada Test Site (NTS) for use in the Teapot series of 1955. These structures required minimum modification for the present use. In addition, since they were isolated from each other, certain of the operations could proceed simultaneously because sources could be used at one or more houses without increasing the radiation background at the other houses.

1.2 OBJECTIVE

The over-all objective of the exercise was to provide specific experimental information on the degree of protection afforded by several residential structures, differing in design and type of construction material, against radiation from distributed sources.

Specific objectives include the following:

1. Determination of the shielding provided by houses against radiation from a contaminated ground plane
2. Determination of the shielding factors for houses against radiation from sources uniformly deposited on the roofs
3. Determination of the effectiveness of various permanent or emergency modifications in improving the shielding factors of the houses
4. Determination of the energy dependence of the shielding factors for gamma radiations from Co^{60} and Cs^{137}
5. Determination of the range of validity of interchanging source and detector (reciprocity) for evaluating shielding factors

A less specific objective was the procurement of information concerning the feasibility of development of a test vehicle for use in radiation measurements on residential structures. This part of the study was the responsibility of personnel of Tracerlab, Inc., and will be reported by them.

This information is made available in its present form to provide results as promptly as possible to those concerned with theoretical and planning studies on radiation protection for the general population.

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Chapter 2

EXPERIMENTAL MATERIALS AND TECHNIQUES

2.1 INSTRUMENTATION

2.1.1 Pocket Ion Chambers

Pocket ionization chambers (PIC's), Victoreen model 362, were used because of their immediate availability in sufficient quantity, reproducibility and accuracy of response, and convenience of use and readability. Victoreen model 240 projection minometers were used for charging and reading the PIC's. Prior to the experiment the energy response and angular response as a function of X and gamma radiation energy were reevaluated. Day[1] had reported the results of such an evaluation of energy response in 1950, and his results were verified. The adverse response (increased reading per unit dose at effective energy* values of less than 300 kev) was readily corrected to within ±10 per cent for effective energies as low as 20 kev by covering the cap end (to one-fourth the over-all instrument length) with 0.040 in. of tin. In addition, the tin greatly improved the angular response. The results of these studies will be published in detail at a later date.

The instruments were calibrated with a radium standard that had been calibrated by the National Bureau of Standards (NBS). A secondary Co^{60} standard was compared to the radium source and taken to NTS for use in checking calibration.

2.1.2 Use of Personnel Monitoring Instruments

Portable survey meters of several types were used for preliminary measurements to estimate exposure times for the PIC's. One set of exposures was made in which the small (8.4-millicurie) Co^{60} standard source was placed at each of two locations in a house, and the area in and about the house (including the roof) was surveyed with a Geiger-Mueller (G-M) type instrument. An ionization-chamber survey instrument was used in another exposure at a house having walls that varied considerably in density from point to point (reinforced-masonry-block house).

2.1.3 Field-laboratory Facility

A 28-ft van type trailer provided with voltage-regulating transformers and air conditioning was used as a field laboratory; it is shown in Fig. 2.1, positioned on blocks for stability and leveling. A partial view of the interior is shown in Fig. 2.2. The boxlike structure on the floor is the source shipping container (4 in. of lead plus $^{3}/_{4}$ in. of iron), which was bolted to the framework of the trailer. The projection type minometers can also be seen in the figure. Shortly after arrival of the trailer at NTS, the sources were removed from the trailer and stored elsewhere to eliminate possible interference with PIC readings.

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*The effective energy of a heterochromatic X-ray beam is the energy of a monochromatic beam that has the same absorption coefficient as the given beam in an incremental thickness of standard filter material.

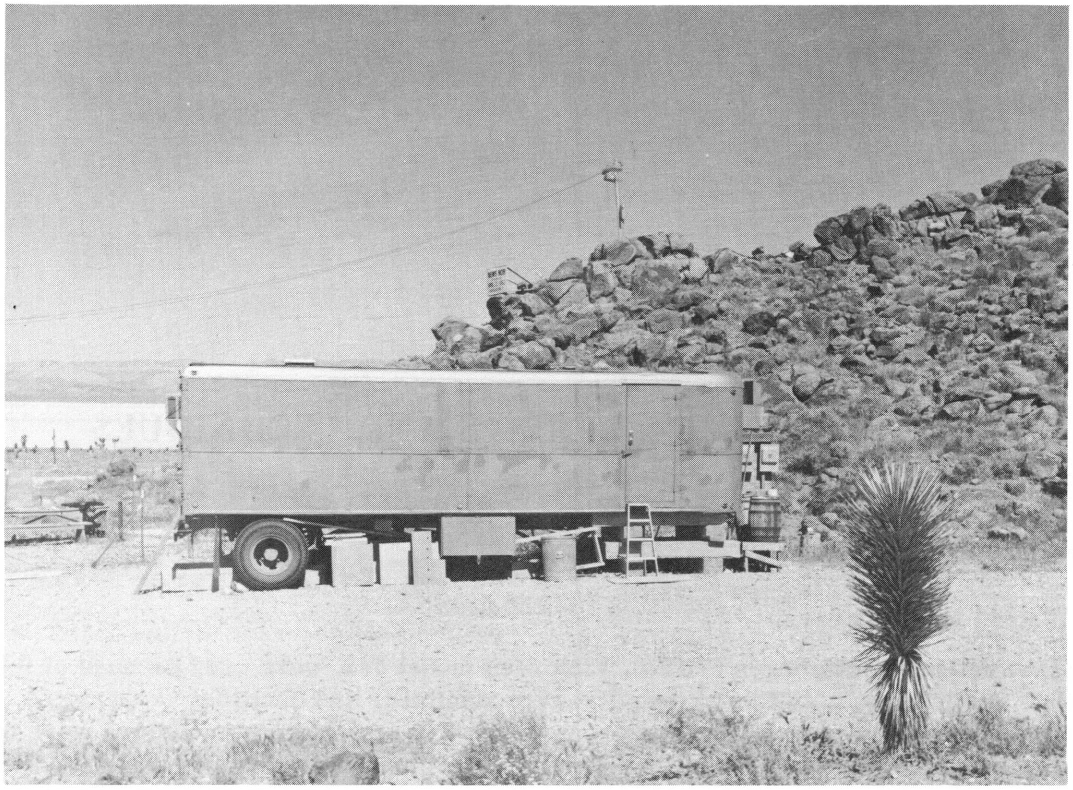


Fig. 2.1 — Mobile-laboratory installation.

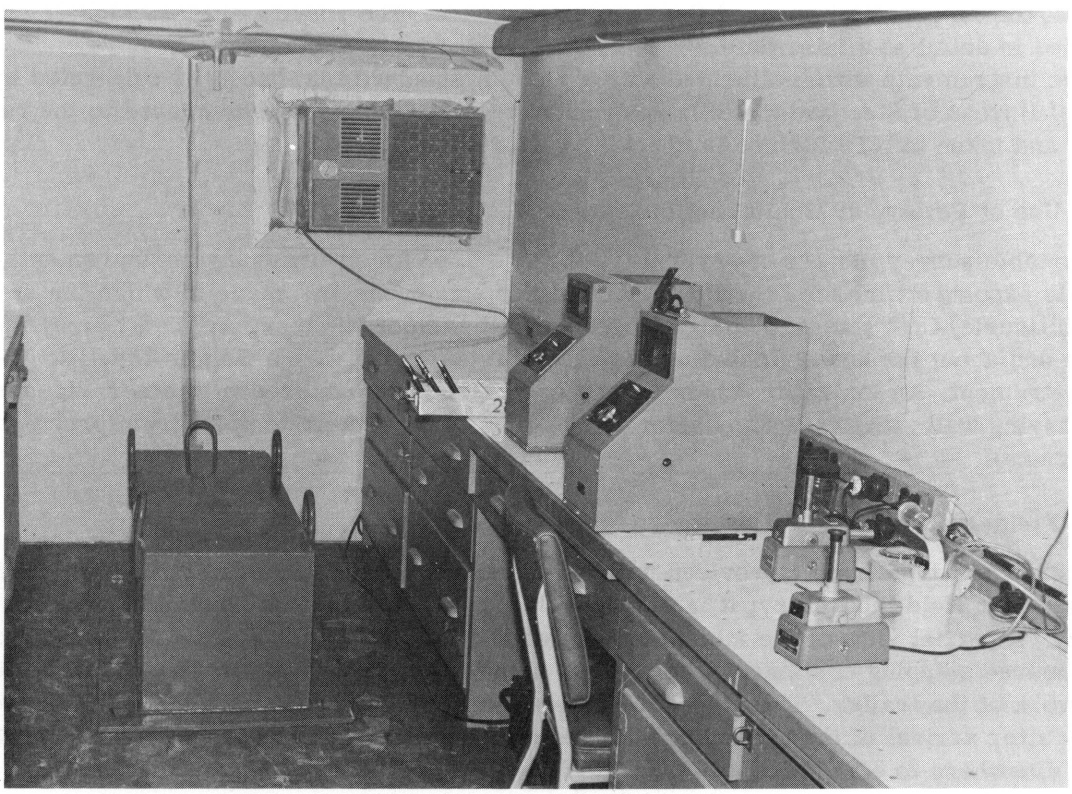


Fig. 2.2 — Partial view of inside of mobile laboratory.

2.2 SOURCES

2.2.1 Production, Encapsulation, and Calibration

The following sources were procured for the experiment:

1. Four hundred 4.15-millicurie Co^{60} sources
2. One 2.10-curie Co^{60} source
3. Twenty 23-millicurie Cs^{137} sources
4. One 1.82-curie Cs^{137} source
5. One 8.40-millicurie Co^{60} source (secondary standard)

To obtain the 400 Co^{60} sources of the desired uniformity of activity of ±5 per cent in the time available, 500 pieces of cobalt (five cans containing 100 sources each) were placed in the Oak Ridge National Laboratory (ORNL) X-10 graphite reactor for three weeks. Based on a 10 per cent random sample, sources from four of the cans were within ±5 per cent of the mean value of 4.15 millicuries.

Fig. 2.3 — Apparatus for putting wire "spine" on source tubes.

The sources were gold plated prior to activation. After activation the sources were cemented with Tygobond at 2-ft intervals into Flexite standard extended plastic tubing of 0.133 in. inside diameter and 0.030 in. wall thickness. One hundred sources were put into tubing on each of four spools. Exposure to temperatures encountered in the desert allowed the tubing to stretch during placement. This stretching was prevented by fastening a flexible wire (stranded and covered field signal wire) with plastic electrical tape midway between sources, i.e., at 2-ft intervals. The lead shields and a source spool used for this operation are shown in Fig. 2.3.

Each of the Cs^{137} sources was sealed in two concentric stainless-steel capsules ($^1/_4$ in. diameter by $1^1/_4$ in. long, outside dimensions). These sources were kept in a small lead container and were not placed in plastic tubing.

The 2.10-curie Co^{60} source was in an aluminum capsule ($^1/_4$ in. diameter by $^5/_8$ in. long).

2.2.2 Calibration

Source calibrations and intercomparisons were made at the Test Site. Each large source was compared to the secondary standard source. The small cesium sources had been checked for uniformity before delivery and were compared as a group; they were placed in pockets in a

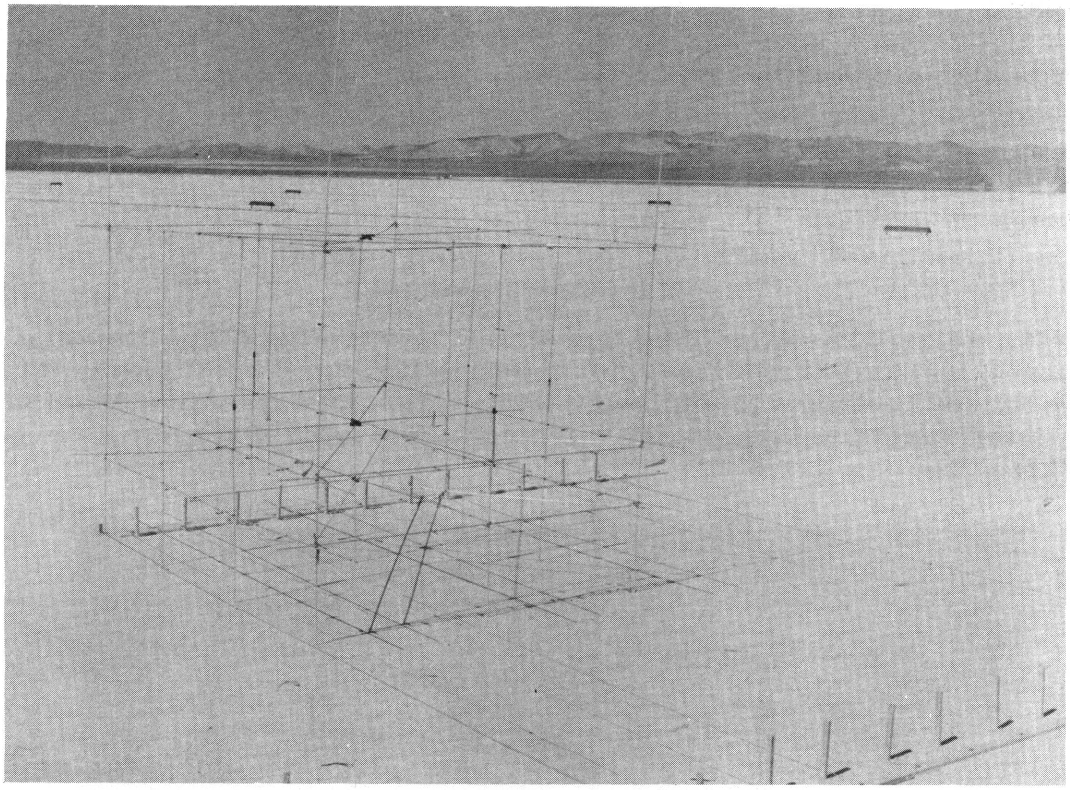


Fig. 2.4 — Phantom house installation.

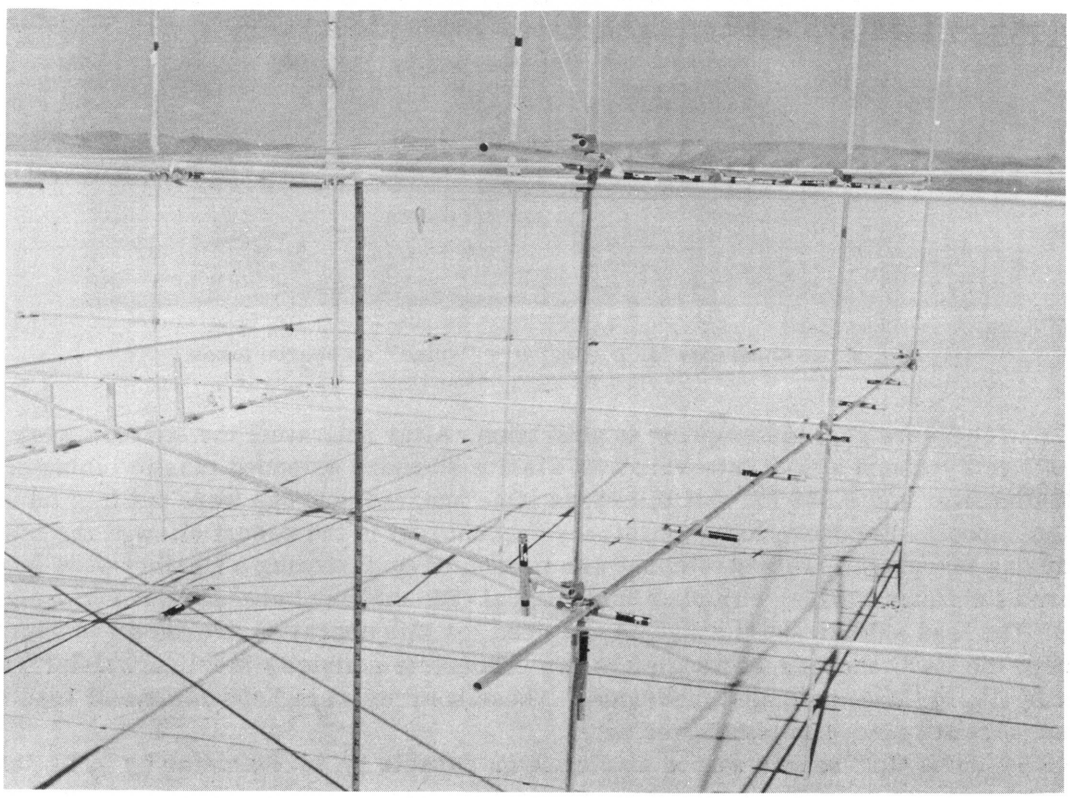


Fig. 2.5 — Close-up of phantom house, showing PIC placement.

4- by 5-in. array on a cardboard holder for comparison. Comparisons were accomplished at a source-detector separation of 10.0 ft and a height of 6 ft 3 in. The tubes containing 100 Co^{60} sources were each wound onto an aluminum spool $^1/_8$ in. in width for calibration. This spool was assumed to be a monolayer coil of sources 2 ft in diameter with negligible self-absorption.

2.3 DESCRIPTION OF STRUCTURES

2.3.1 Phantom House

A series of measurements with no attenuating material between the source and the detector was required to serve as a basis for evaluation of attenuation. A "phantom house" was defined, comprising an area equivalent to that of the two-story wood frame house, on the dry lake bed of Yucca Flat, a large unobstructed level plain. A framework of thin-walled ($^1/_2$ in. diameter) aluminum tubing fastened with standard laboratory clamps was erected to hold the PIC's

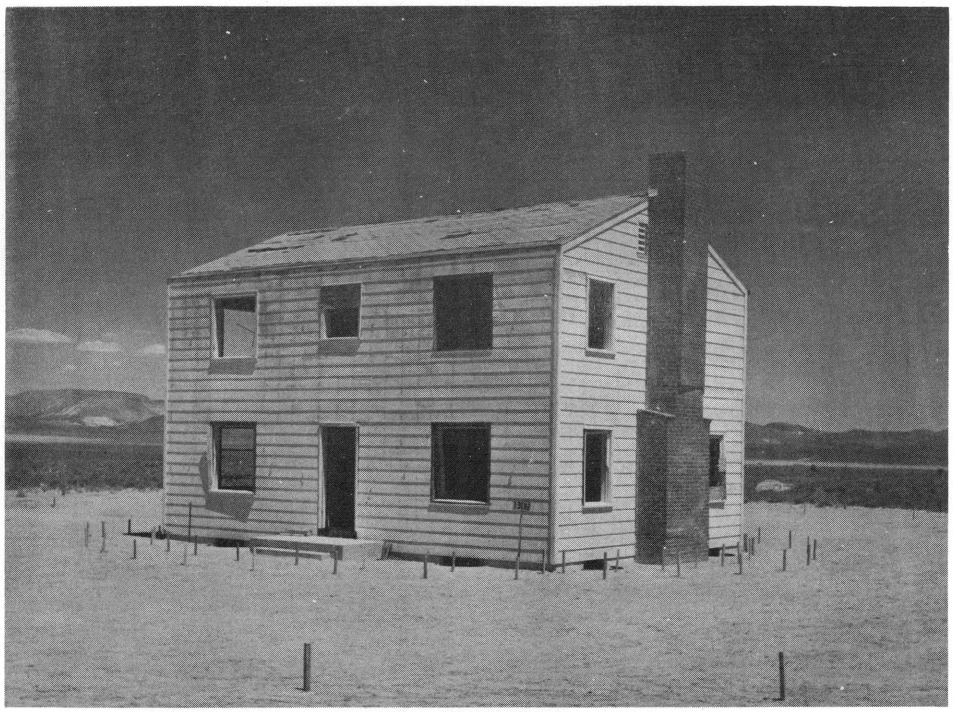


Fig. 2.6—The 2SWF house.

(Fig. 2.4). The one-quarter house was 16 by 12 ft. The frame included horizontal tubes at the 3-, 5-, and 11-ft levels and vertical members at the corners extending to 15 ft. The PIC's were taped to the support tubing at appropriate intervals (Fig. 2.5). The axes of the PIC's were placed horizontally for the "floor" exposures and vertically for the circular ring exposures.

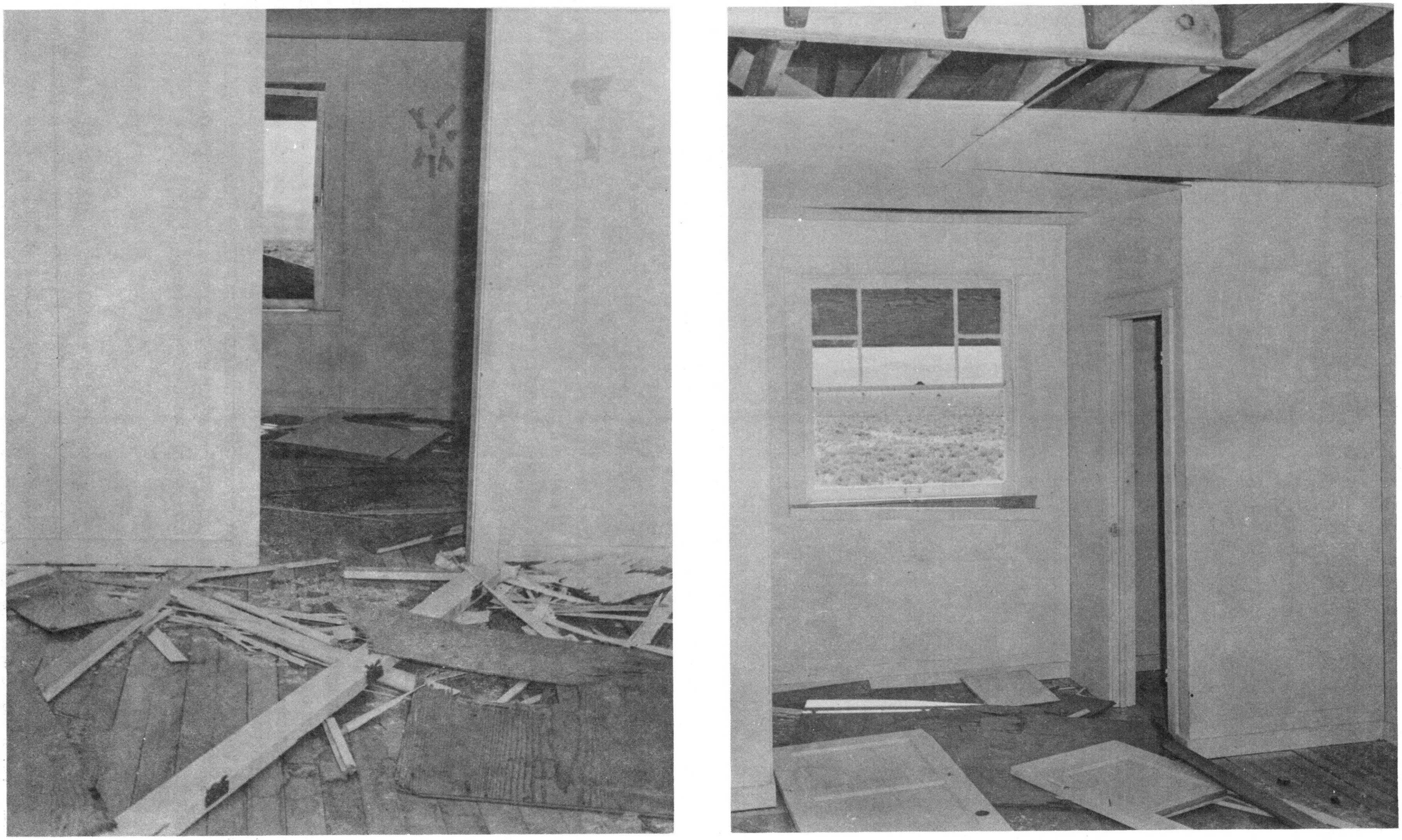
2.3.2 Two-story Wood Frame (2SWF) House

This house was a two-story frame house having a center hall and a basement with a reinforced-concrete foundation (Fig. 2.6). The exterior dimensions of the house were 24 ft 8 in. by 33 ft 4 in. The house is similar in layout to houses that suffered blast damage in the 1953 test series; however, some design changes were made, based on the results of that test program, to strengthen the structure as much as possible within an increase of approximately 10 per cent in the building cost. A brief description of this house and also of the others used in this exercise with additional pictures are included in Report ITR-1194, Operation Teapot. All framing was of 2- by 4-in. studs placed 16 in. apart. Exterior walls contained about 2 in. of wood siding, and interior walls were faced with $^3/_8$-in. plywood (Figs. 2.7 and 2.8). The first

(a)

(b)

Fig. 2.7—Inside view of the 2SWF house, indicating materials and relative thickness (prerepair).



(a) (b)

Fig. 2.8—Inside view of the 2SWF house, indicating materials and relative thickness (prerepair).

floor was supported by 2- by 10-in. joists; the second floor, by 2- by 8-in. joists; the attic floor, by 2- by 8-in. joists; and the roofing, by 2- by 10-in. rafters, all spaced on 16-in. centers. The basement was made of 8-in. reinforced-concrete exterior walls and three 8-in. interior walls, two of which served as the walls of a concrete basement shelter. In addition,

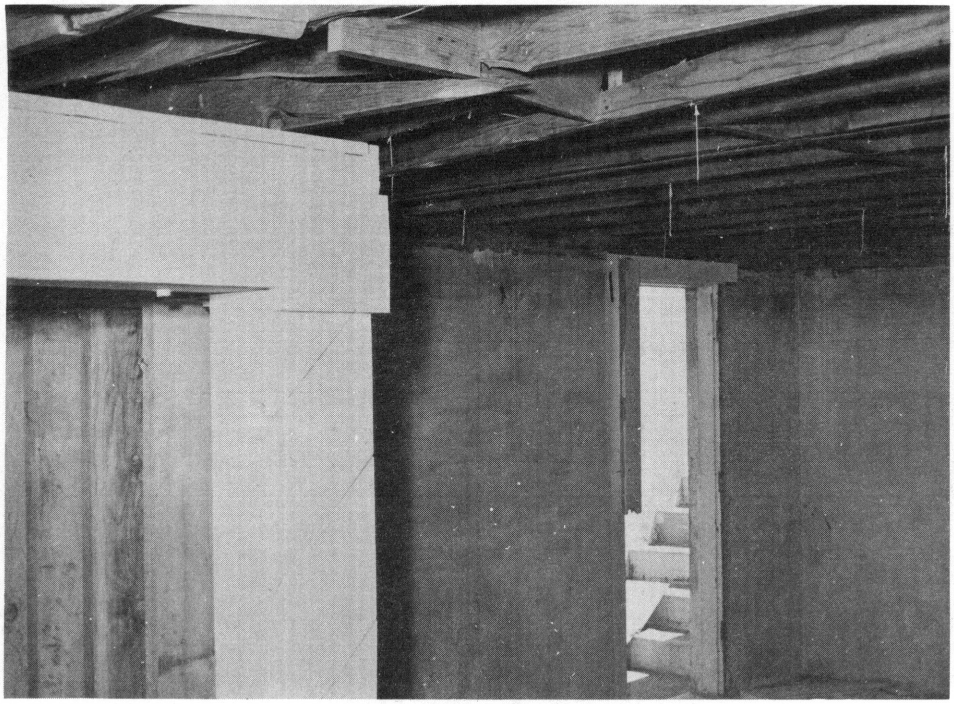


Fig. 2.9 — Partial view of the basement of the 2SWF house, showing exterior areaway and debris shelter.

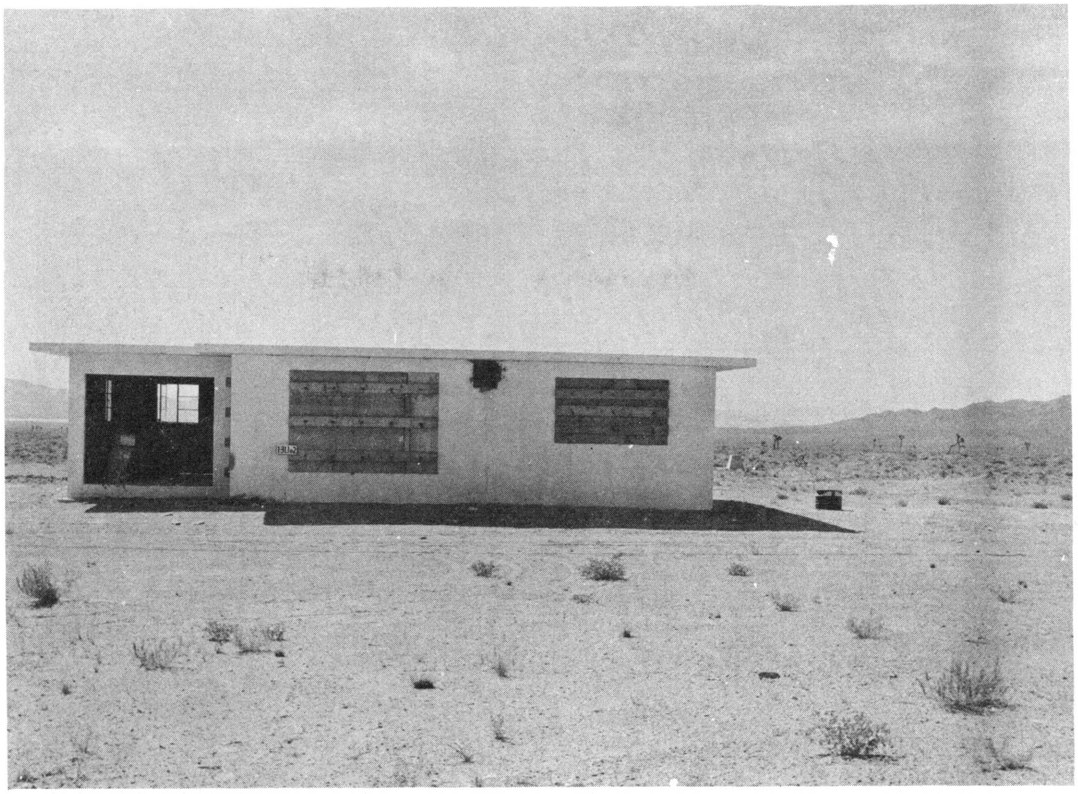
there was a wood-frame basement shelter in one corner (Fig. 2.9). The area surrounding the house was cleared and leveled out to a distance of 65 ft from the center of the house. The variation in elevation was less than 1 in. within this cleared area. A similar area was cleared around each house used in this exercise.

2.3.3 One-story Precast Concrete (PCC) House

This single-story house was constructed on a concrete floor slab. It consisted of precast lightweight (98 lb/cu ft) expanded shale-aggregate concrete walls and partition panels, which were joined by welding matching steel lugs, and similar flat-roof panels anchored to the walls by special countersunk and grouted connectors to the wall steel. Figure 2.10 shows two exterior views of this house, and Fig. 2.11 shows an interior view. All panels were 6 in. thick. The outside dimensions were 40 by $27\frac{1}{2}$ ft, exclusive of a 2-ft overhang on all sides. The thick wooden window coverings shown in Fig. 2.11 were removed, but for exposures 28 and 29 the living-room (northeast) window and door were filled with $3\frac{1}{2}$-in.-thick concrete blocks (151 lb/cu ft). It was not expected that the thin-walled steel pipe previously installed in certain rooms of this house would produce anomalies in the measurements.

2.3.4 One-story Wood Frame Rambler (WR)

This house was of conventional design except that it contained an aboveground shelter consisting of bathroom walls, floor, and ceiling of 8-in. reinforced concrete, with a blast door and window shutter. The outside dimensions were 40 ft by 25 ft 4 in. (Figs. 2.12 and 2.13). The interior walls were faced with $\frac{1}{2}$-in. plasterboard.



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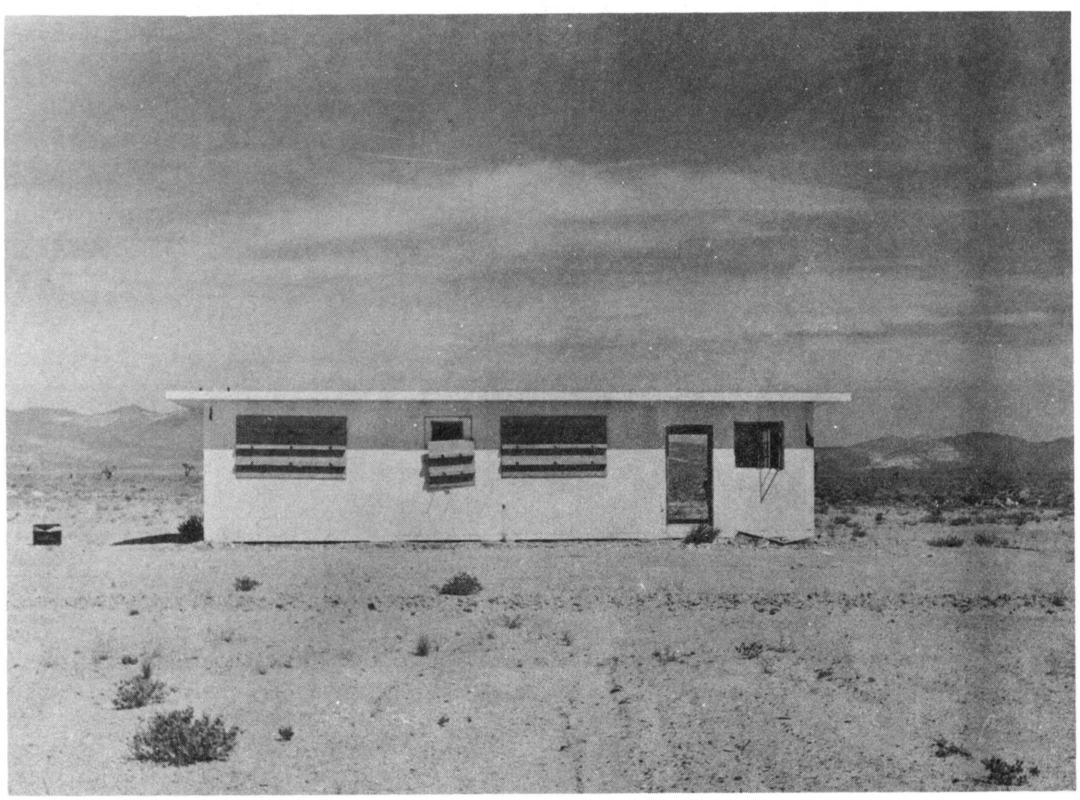
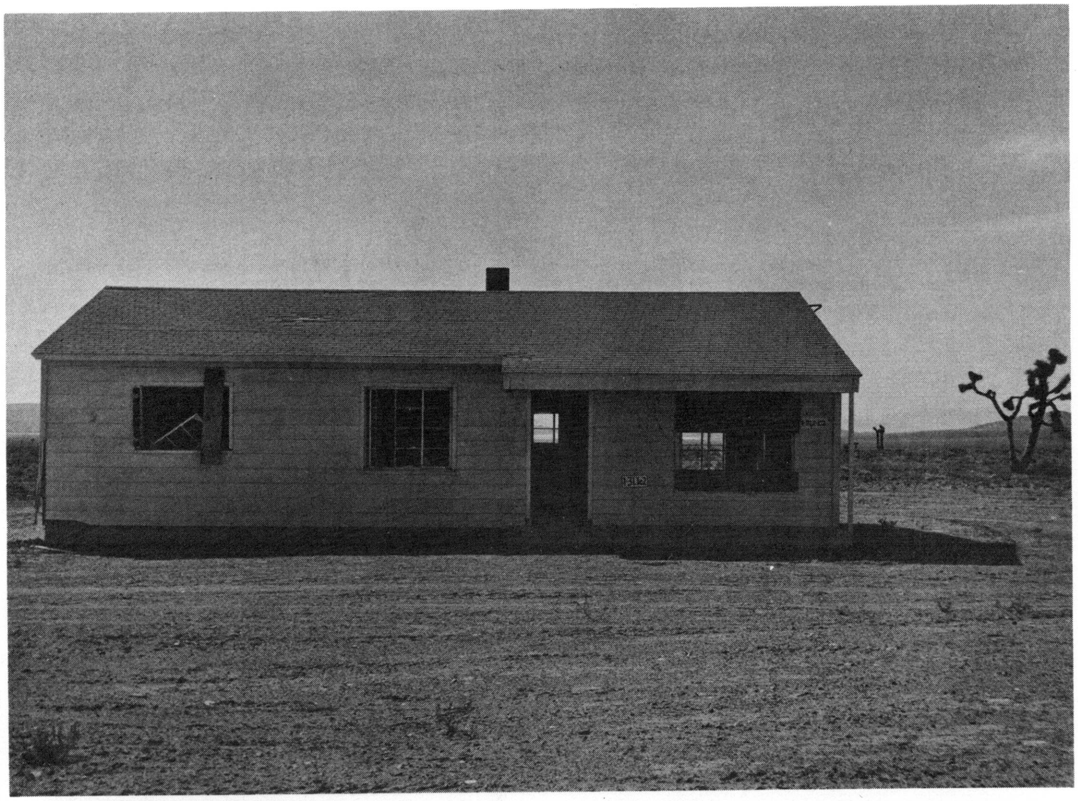


(b)

Fig. 2.10 — PCC house (a) front and (b) rear views.

Fig. 2.11 — PCC house living-room interior.



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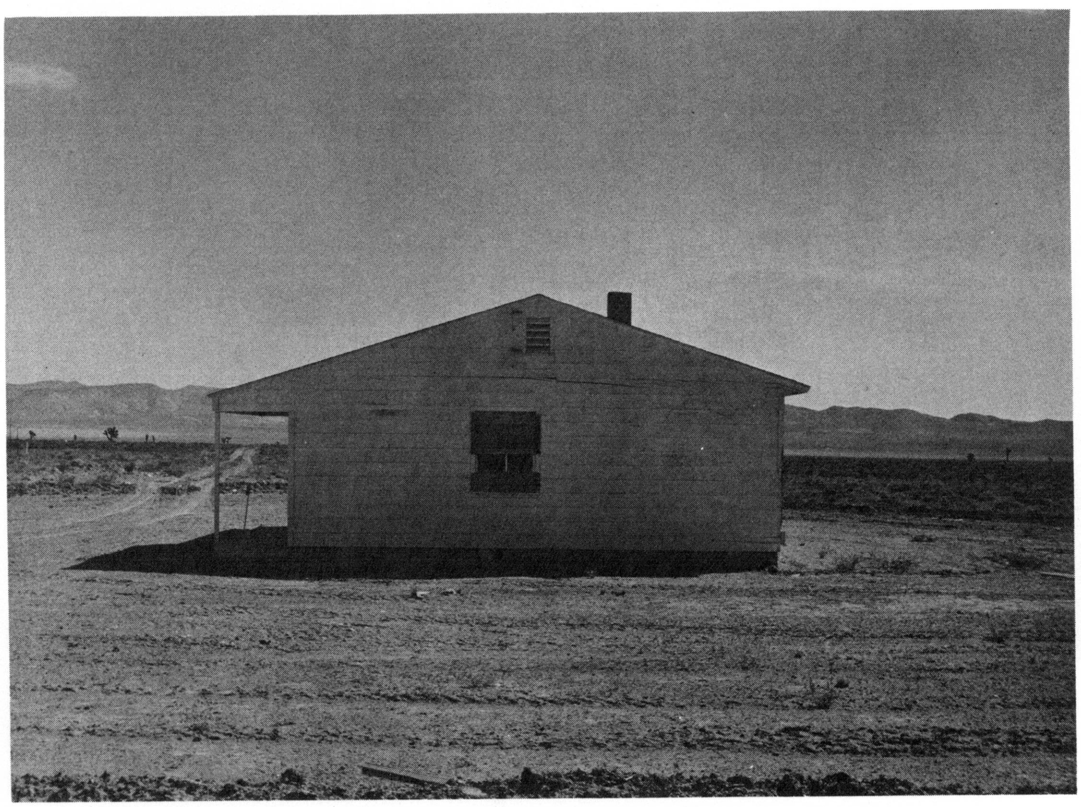

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Fig. 2.12—Rambler house (a) front and (b) east-end views.

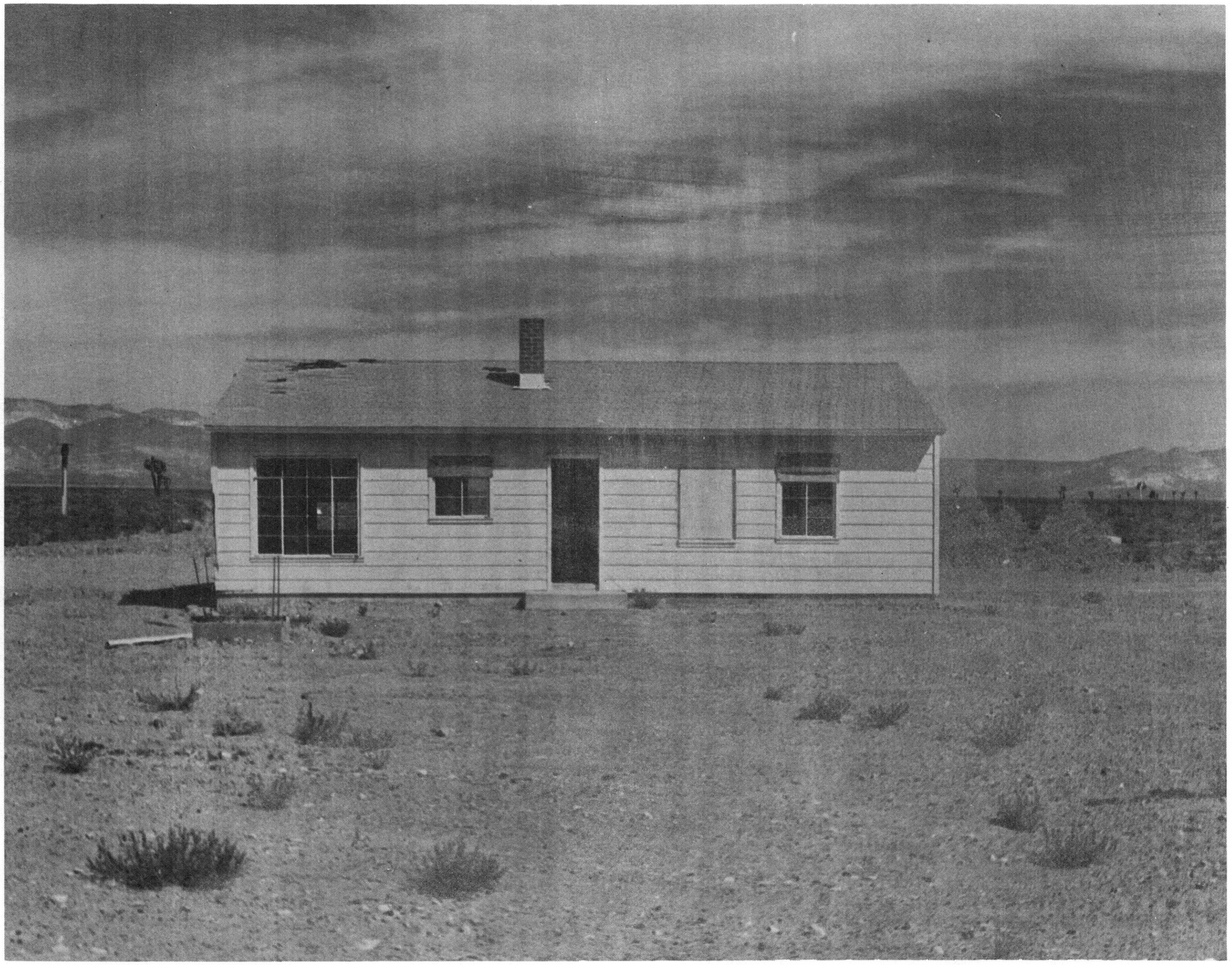
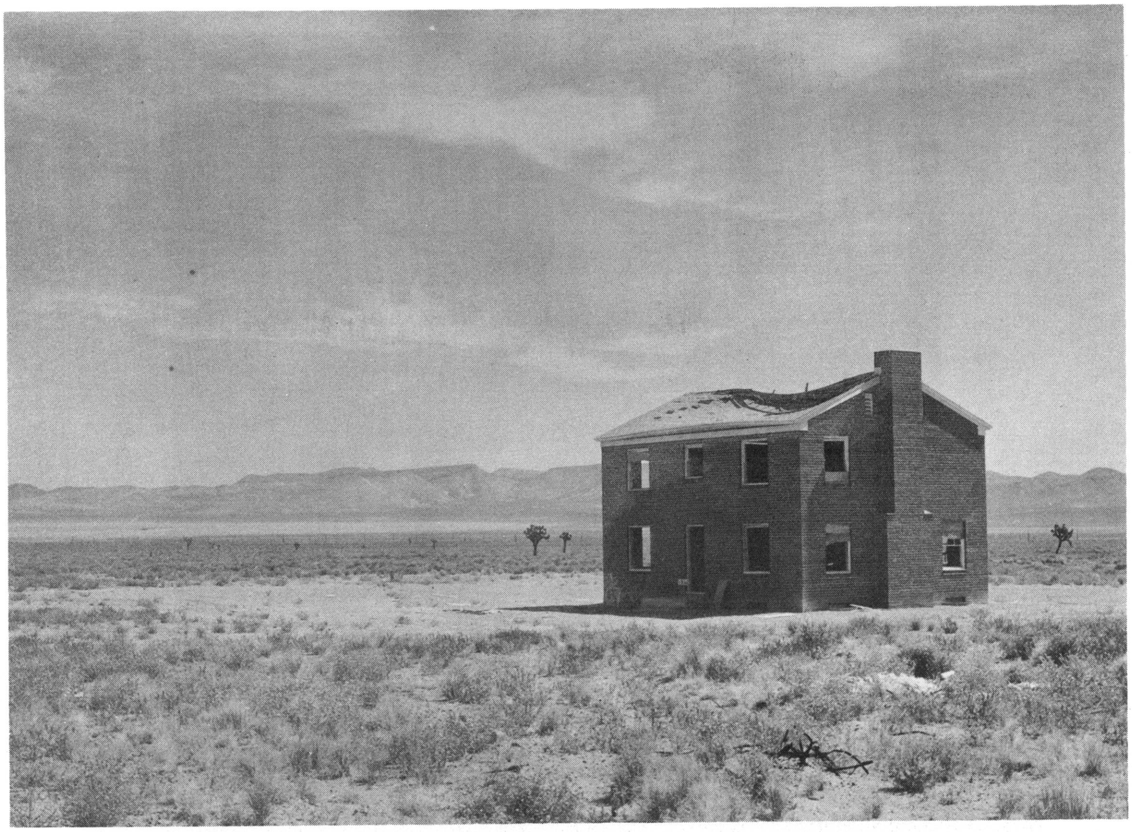


Fig. 2.13—Rambler house rear view.



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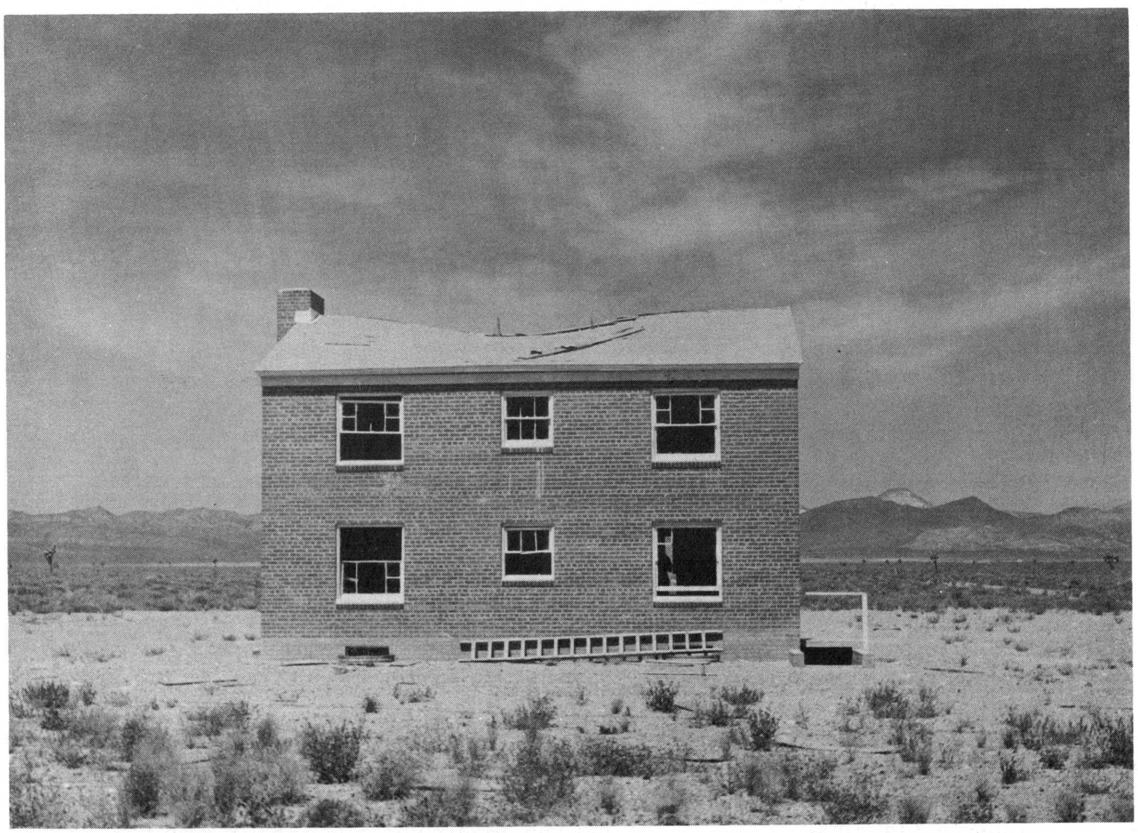


(b)

Fig. 2.14—The 2SB house (a) front-quarter and (b) rear views.

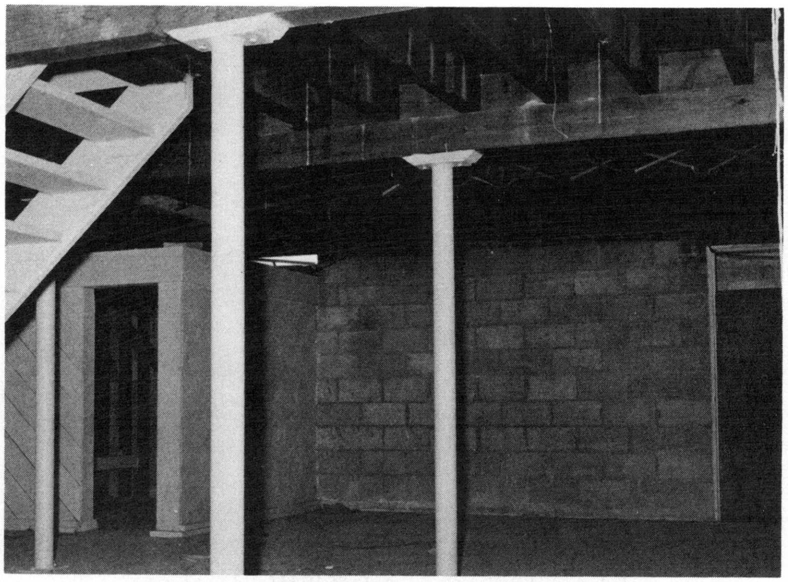


Fig. 2.15—The 2SB house basement.

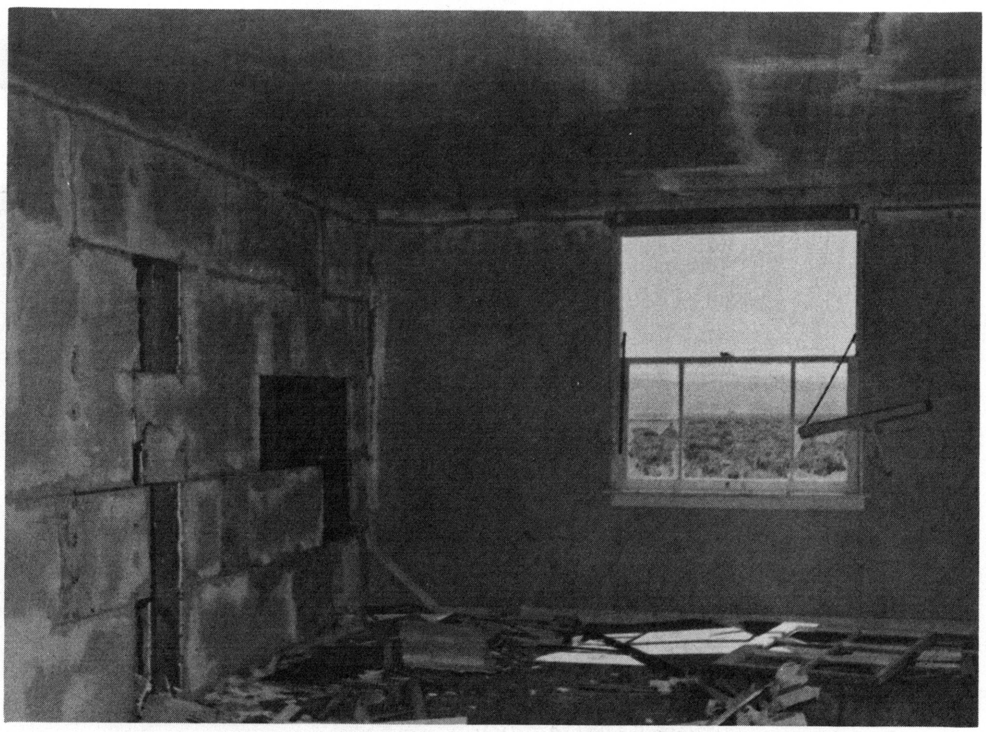
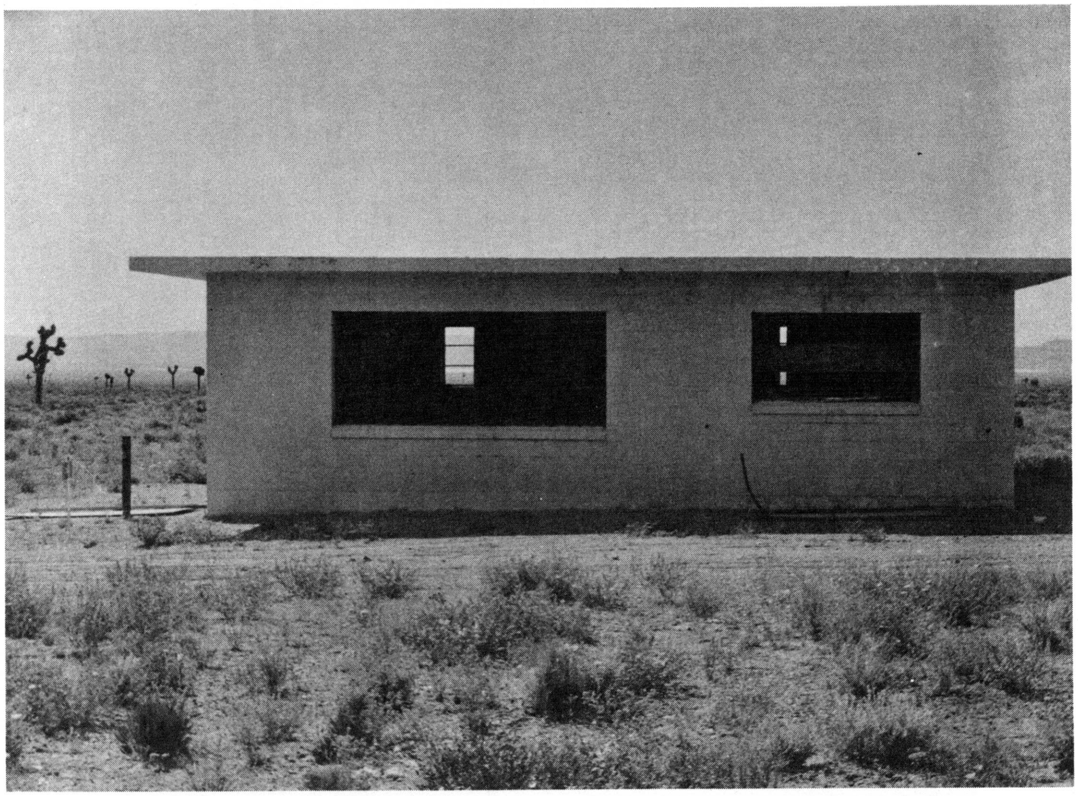


Fig. 2.16—Plasterboard-plaster arrangement in the 2SB house before repairs.

2.3.5 Two-story Brick (2SB) House

This house was a two-story and basement, center hall, wall-bearing house of 4-in. brick and 4-in. cinder block, with floors, partitions, and roof of wood framing and basement foundation walls of cinder block (Figs. 2.14 and 2.15). It is similar in design and layout to the two-story frame house described in Sec. 2.3.2, but the construction generally was conventional, no attempt having been made to strengthen the house through special design. The roof had been so severely damaged that it was judged to be inexpedient to repair it for use during this exercise. Interior wall construction in this house was of sheet rock (Fig. 2.16).



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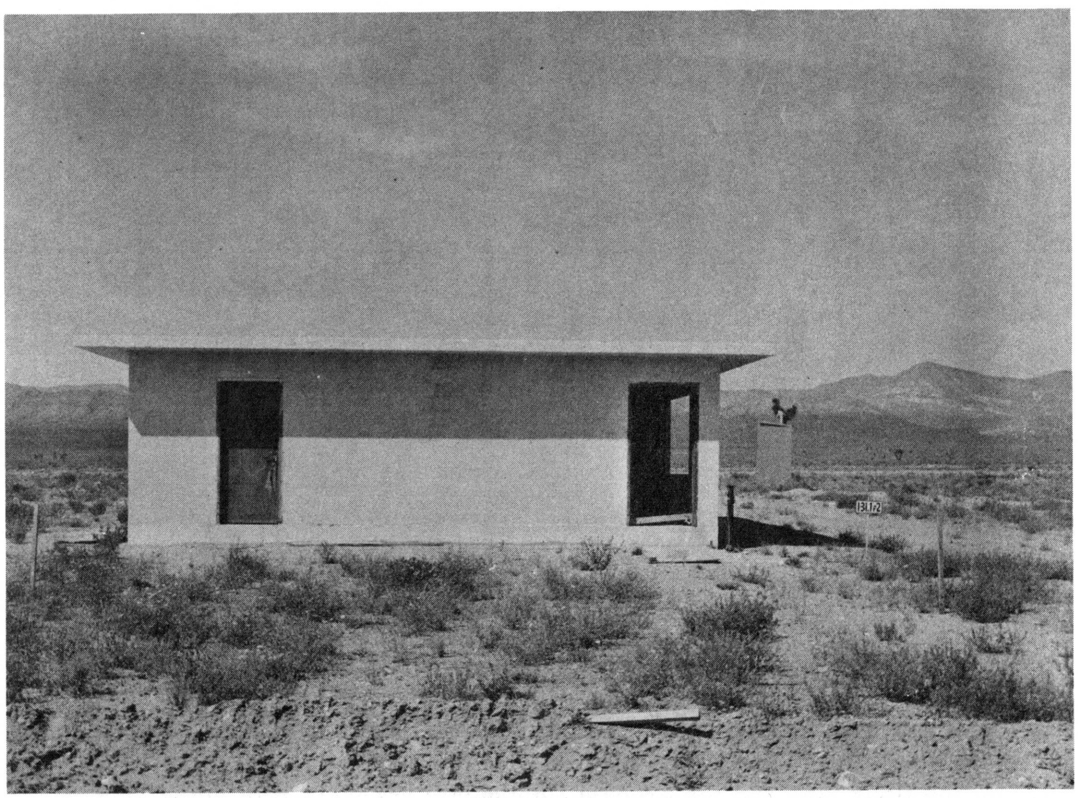
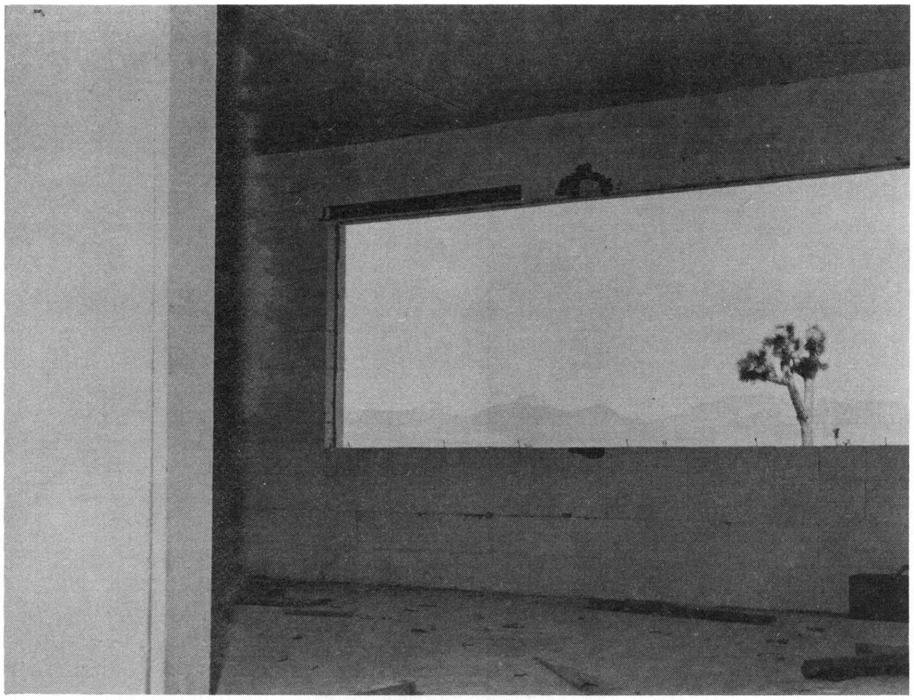


(b)

Fig. 2.17—Exterior of reinforced-concrete-block house.



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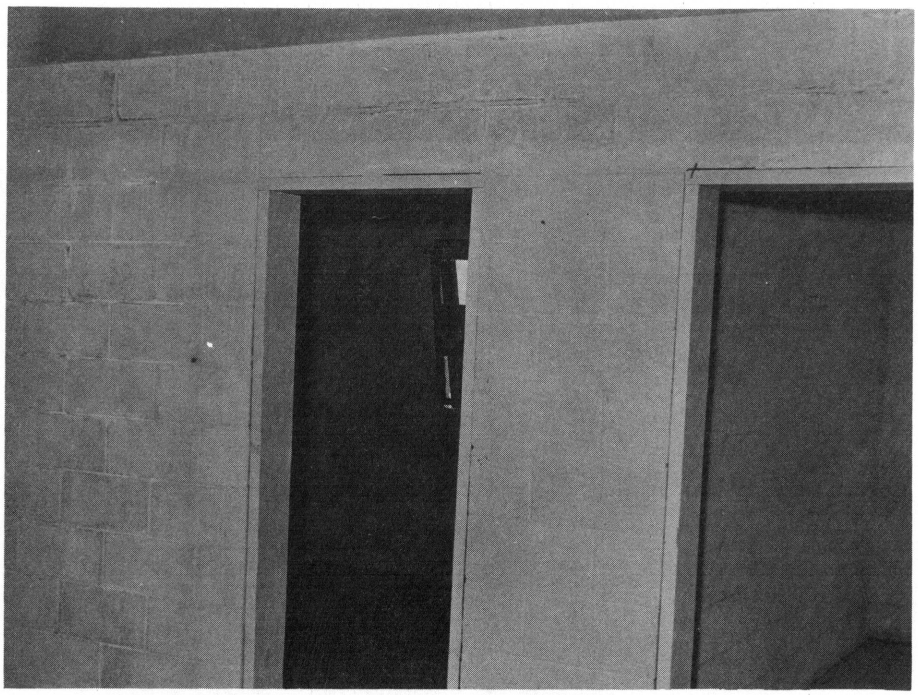


(b)

Fig. 2.18—Interior of reinforced-concrete-block house.

2.3.6 Reinforced-masonry-block (RMB) House

This was a one-story house built of reinforced expanded shale-aggregate masonry blocks (Fig. 2.17). The 8-in. walls and partitions were reinforced with steel rods, which were anchored into the floor slab and the precast lightweight concrete roof slabs (Fig. 2.18). The walls were also reinforced with horizontal steel at two levels, and openings were spanned by reinforced lintel courses. The outside dimensions were 29 ft 4 in. by 27 ft 4 in., exclusive of a 2-ft roof overhang. Owing to the presence of hollow and filled cores, the density and hence the attenuation for gamma radiation was expected to vary widely from point to point.

2.3.7 Elevation Relative to Average Ground Level

The elevations of the various components of the test houses relative to the average ground level are shown in Table 2.1.

TABLE 2.1—RELATIVE ELEVATIONS

House	Basement floor	Foundation	First floor	Second floor	Roof peak	Roof slope
2SWF	6 ft 6 in.	$6^3/_4$ in.	1 ft 8 in.	9 ft 10 in.	24 ft $2^1/_2$ in.	5:12
PCC			2 ft $^1/_2$ in.		10 ft $6^1/_2$ in.	Flat
WR			1 ft $7^5/_8$ in.		14 ft 6 in.	4:12
2SB	6 ft $7^1/_2$ in.	3 in.	1 ft $6^1/_2$ in.	9 ft $8^1/_2$ in.	24 ft $^3/_4$ in.	5:12
RMB			1 ft		9 ft 6 in.	Flat

2.4 OPERATIONAL PROCEDURES

2.4.1 Radiation Background

Radiation background surveys were made at each of the locations to be used. Although the general area had a detectable low-level contamination, readings taken after grading and leveling had been completed indicated that, in general, no background corrections to the PIC readings would be necessary for this exercise. The background immediately surrounding the two-story wood frame house, however, was approximately 0.04 mr/hr, as measured with the portable G-M survey instrument; this limited the extent of the area in which instruments were placed in exposure 41.

2.4.2 Source Handling and Personnel Exposures

Since the amount of activity to be handled was relatively large and the number of personnel was limited, it was important that an efficient means of source manipulation be used. It was sufficient to use source-handling tongs 7 ft long for all sources except the 400 Co^{60} sources. The 200-ft lengths of tubing containing 100 sources were each unreeled and placed in long ditches when not in use. Each length could be grasped at the end by tongs and dragged into position quite easily. The personnel exposures were within the limits recommended in NBS Handbook 59.

2.4.3 Ground-plane Distributions

For ground ring exposures the tubes containing the sources were guided into position by accurately placed stakes, as shown in Fig. 2.19. The stakes were placed in concentric circles, the radii of which were determined by the requirement that the circumferences times an integral number of turns equal the total length of the tubing. The range of the radii was determined by the outer dimensions of the house and the minimum measurable dose rates. Table 2.2 gives the ground ring radii.

To fill in the areas between the innermost circle and the edge of the 2SWF house, the strips were arranged in such a manner that each source represented an area of 4 sq ft.

For the finite rectangular source distribution at the phantom house, pulleys attached at 2-ft intervals to boards were used to position the sources. This produced an array of sources spaced 2 ft apart over an area 24 by 32 ft (Fig. 2.20).

2.4.4 Roof and Gutter Exposures

The same apparatus was used to position the sources on the roof of the two-story wood frame house. However, owing to mechanical difficulties its use was discontinued, and for the remaining 2SWF house roof exposures the source strips were laced around large nails. The source strips were also laced around masonry nails for roof exposures on the flat roof of the precast concrete house. The Cs^{137} sources were positioned on masking tape as a precaution against subsequent movement.

For the exposure in which the Co^{60} source tubes were placed on the rear gutter of the 2SWF house (exposure 38), two 200-ft lengths were individually folded into 33-ft lengths and taped together with cords attached to each end. These could then be carried into position by personnel on ladders at the ends of the house.

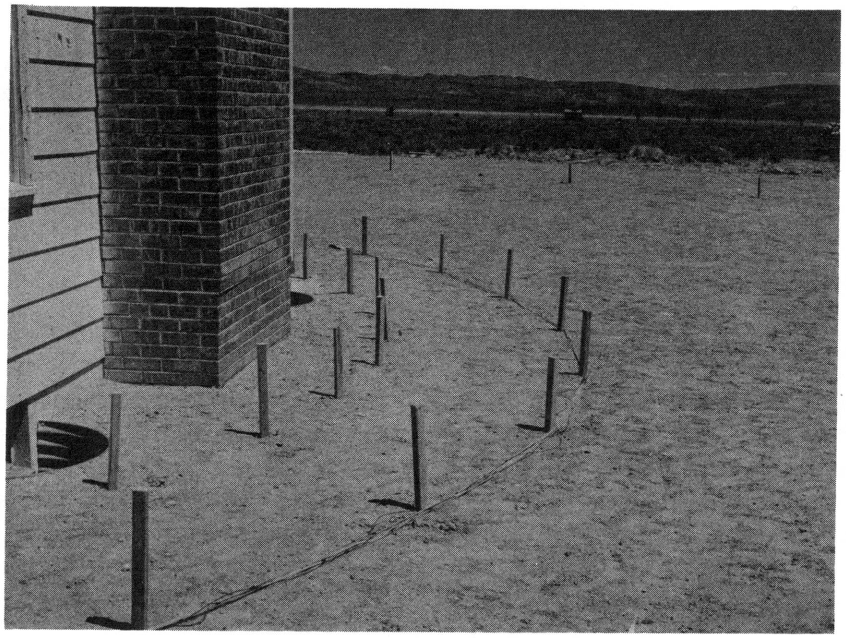


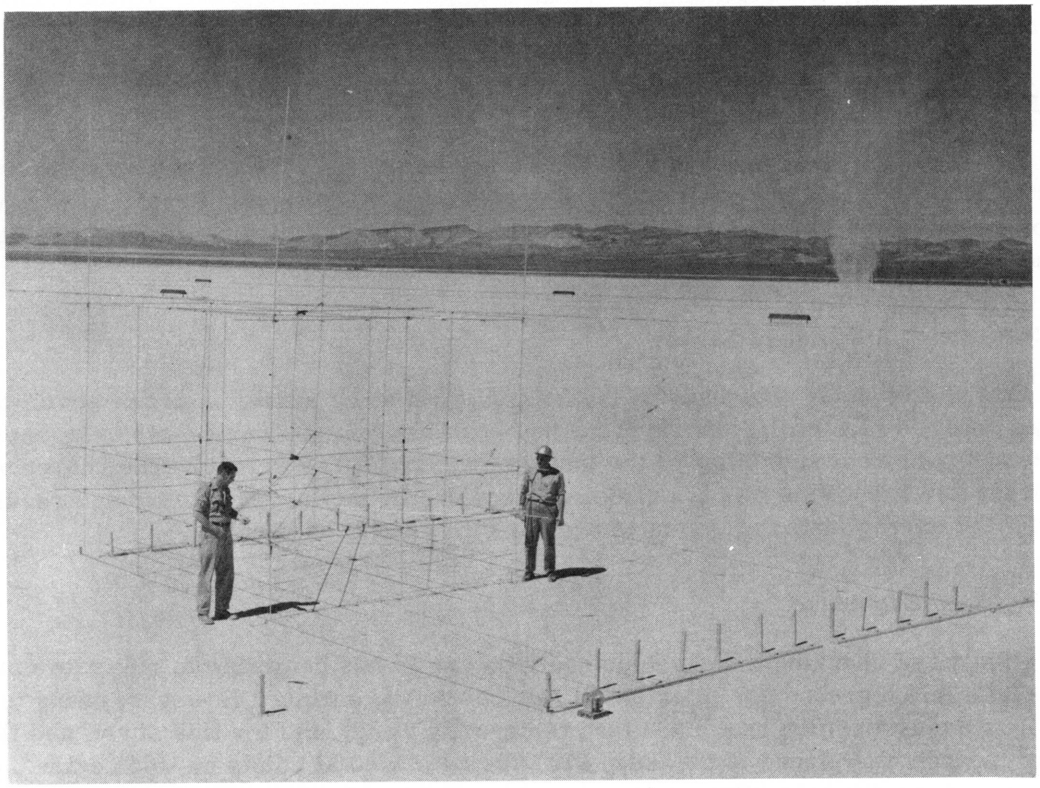
Fig. 2.19—Source ring placement at the 2SWF house for ρ = 25.5 ft.

TABLE 2.2—GROUND RING RADII

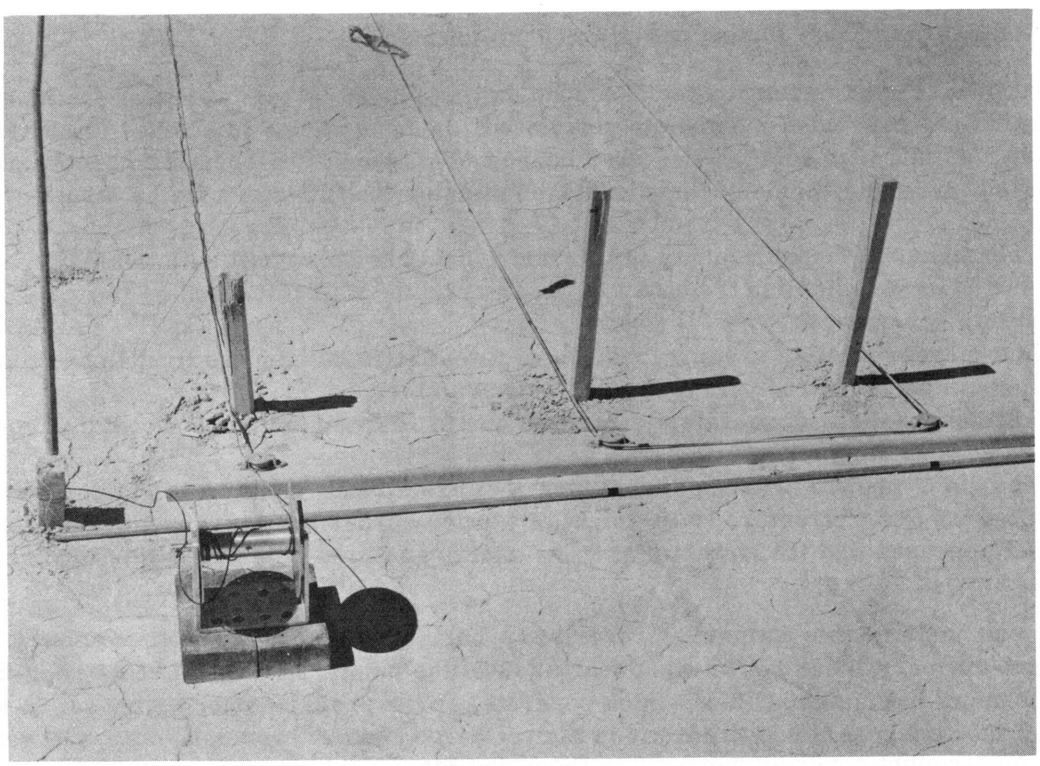
No. turns, n	Radius
1	127 ft 4 in.
2	63 ft 8 in.
3	42 ft $4^1/_8$ in.
4	31 ft 10 in.
5	25 ft $5^5/_8$ in.
6	21 ft $2^5/_8$ in.

2.4.5 Reciprocity Placement

The experimental procedures could have been simplified and the measurements could have been made more generally useful if it had been established prior to the experiment that measurements utilizing reciprocity could be made with sufficient accuracy. However, since there was insufficient data available concerning reciprocity, it was important that measurements be made with both single- and multiple-source arrays. Since sufficient time was not available for a comprehensive study of the limits of applicability of reciprocity, an abbreviated series of measurements was made. The 2.1-curie Co^{60} source (or the 1.82-curie Cs^{137} source) was placed at a point of interest in a house, and PIC's were placed at points on the roof and ground corresponding to points in the ring or roof source-distribution patterns used for the small sources. Instruments used outside after dawn or before dusk were wrapped in aluminum foil. In general, all measurements requiring outside placement of PIC's were conducted from dusk to shortly after dawn. As a check on the temperature effect, the electrode was removed from



(a)



(b)

Fig. 2.20 — Phantom house with pulley boards in place.

one instrument, and a thermometer was inserted. When this PIC, wrapped in aluminum foil, was placed in the sun, the thermometer inside registered essentially the "in-the-shade" temperature.

2.4.6 Energy Dependence and Angular Response

On the first exposures made, the tin foils discussed in Sec. 2.1.1 were used on several of the PIC's. Both bare and tin-covered PIC's were placed in orthogonal arrays at each of several points of measurement. There was never a significant difference in the various readings, and on subsequent exposures only a few check points were used.

2.4.7 Monitoring Instrument Survey

An abbreviated study was made of the feasibility of using survey instruments (G-M type) and small sources (8.4-millicurie Co^{60}) for house attenuation measurements. The energy dependence and poor reproducibility of the instrument were borne in mind. The source was positioned in the 2SWF house at points previously occupied by the larger source, and readings were made with the survey meter at points where the PIC's had been used.

2.4.8 Skyshine Exposure

As a means of checking the skyshine contribution, it was desirable to measure the dose rate in a hole in the ground due to extended sources on the surface. However, owing to time restrictions the assumption was made that reciprocity would hold for this study, and the 2.1-curie Co^{60} source was placed in the hole, PIC's being placed at points on lines extending directly away from the hole. Except for ground penetration to the nearest PIC, the dose rate was too low for accurate measurement in the time available.

2.4.9 Relative Emphasis Placed on the Various Houses

Throughout the experiment special emphasis was placed on the two-story frame house. Time limitations precluded a complete study of all the houses, and this house presented several aspects in common with some of the other houses. This permitted certain intercomparisons and checks to be made. Some of the advantages of using the two-story frame structure were as follows:

1. The basement measurements in this house could be compared with those of the two-story brick house to establish the effect of superstructure wall thickness on the radiation scattered into basements.
2. In a manner similar to item 1, the dose-rate distribution on the first floor from ground radiation could be compared with that of the wood rambler.
3. The second-floor dose-rate distribution due to sources on the roof could be compared to that of the wood rambler.
4. The 2SWF house had three debris type shelters already constructed in the basement: a thick-walled concrete structure (8 in. thick), a wooden corner shelter, and a wooden lean-to shelter. It appeared that the first two of these shelters offered potential fallout protection and should be studied.

The emphasis on this structure prescribed a certain deemphasis on other houses. The reinforced-masonry-block house was deemphasized the most. This house had a roof of the same thickness and material (6-in.-thick concrete) as the precast concrete house. In addition, certain of the concrete blocks from which the reinforced-masonry-block house was constructed had standard-weight concrete poured into them, but others did not. This increased considerably the variation in attenuation at adjacent points. Since it could not be ascertained which blocks contained the added concrete, interpretation of any extended-source data would have been further complicated. Therefore only measurements utilizing a single source and an ionization survey instrument were made for this house.

(Text continues on page 44.)

Fig. 2.21—Basement window well before sandbagging.

Fig. 2.22—Sandbagged basement window well.

Fig. 2.23—Interior view of basement window well with sandbags in place.

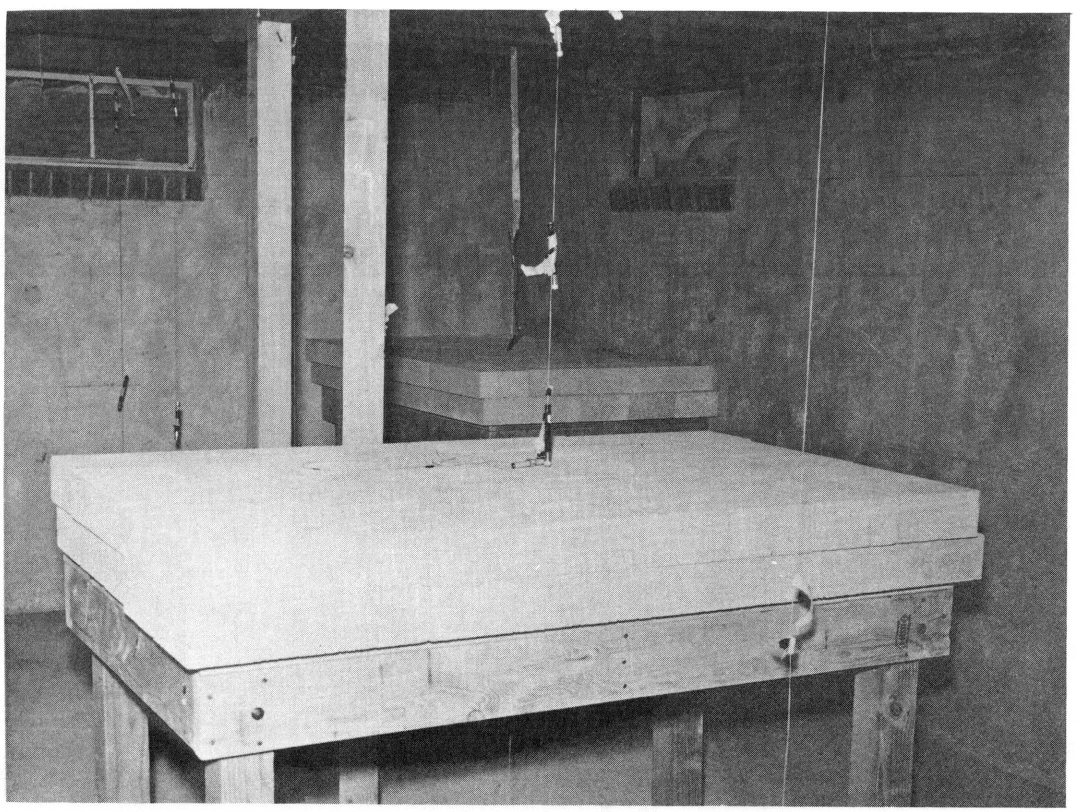


Fig. 2.24—Basement interior (2SWF) with sandbags in windows and concrete blocks on tables.

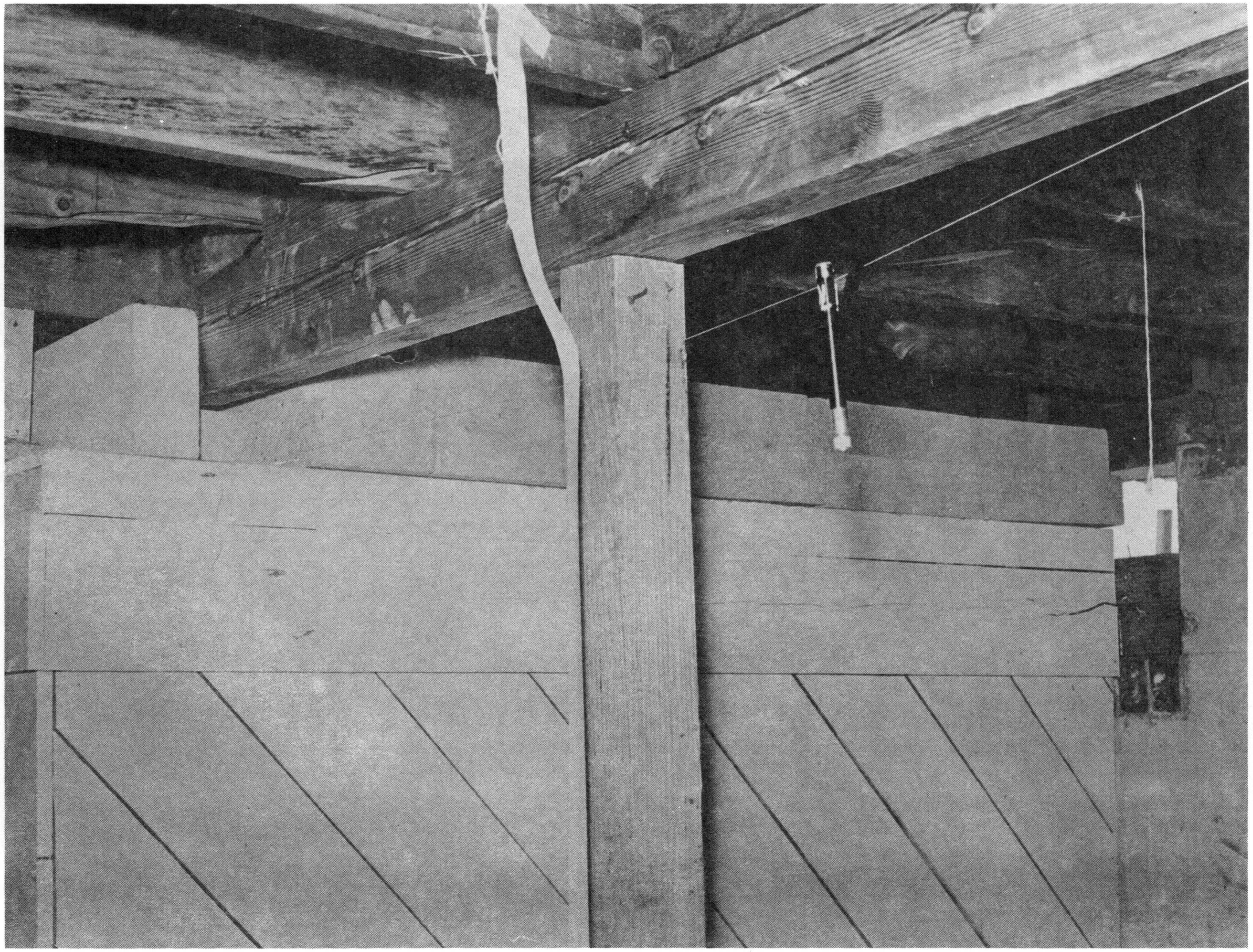
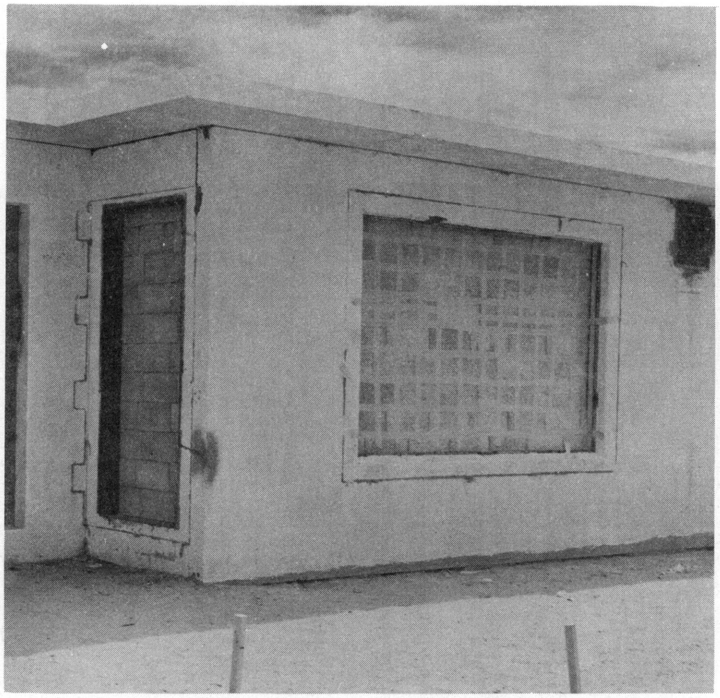
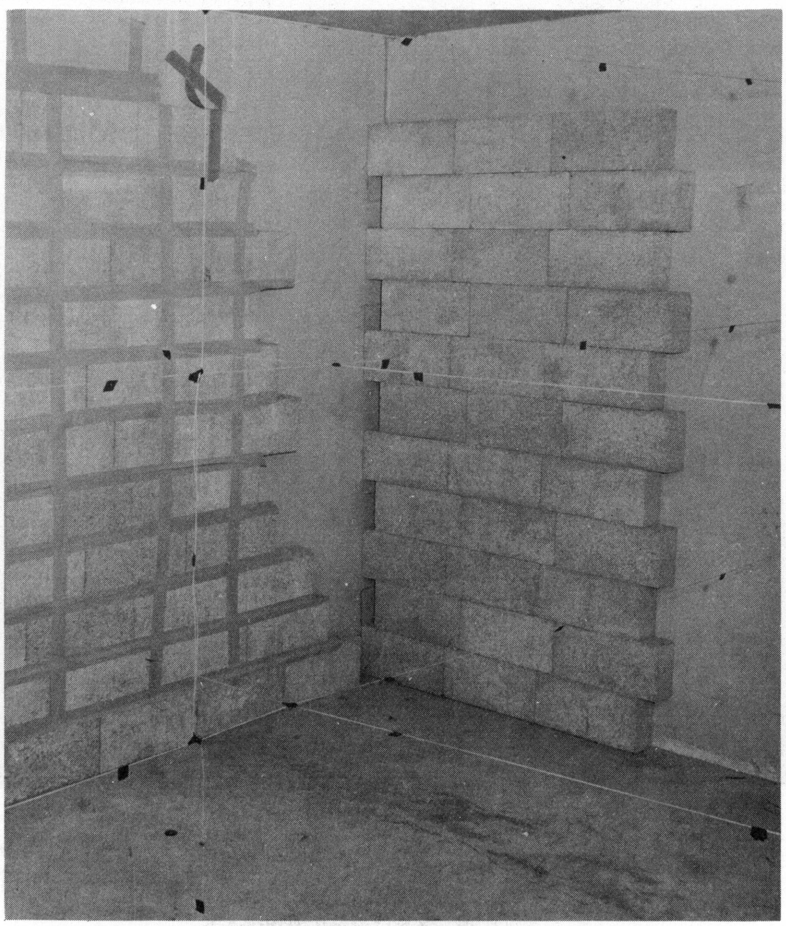


Fig. 2.25—Corner debris shelter in the 2SWF house with concrete blocks ($7\frac{1}{4}$ in. high) on top.

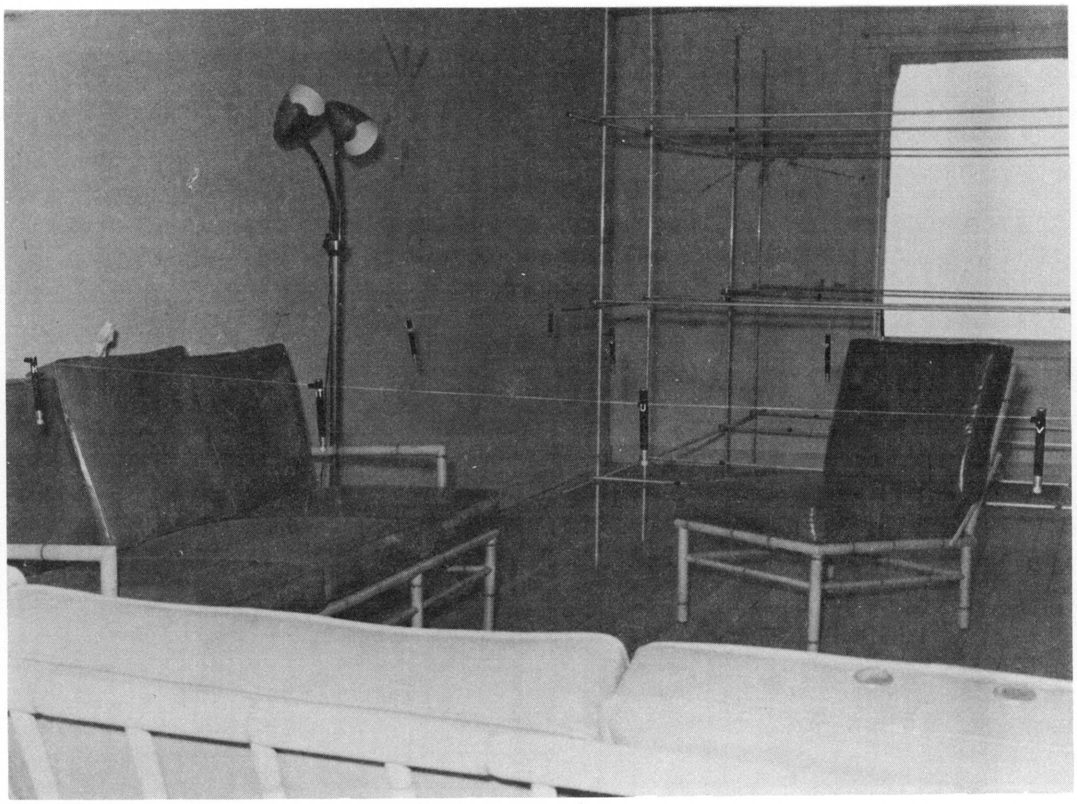


(a)

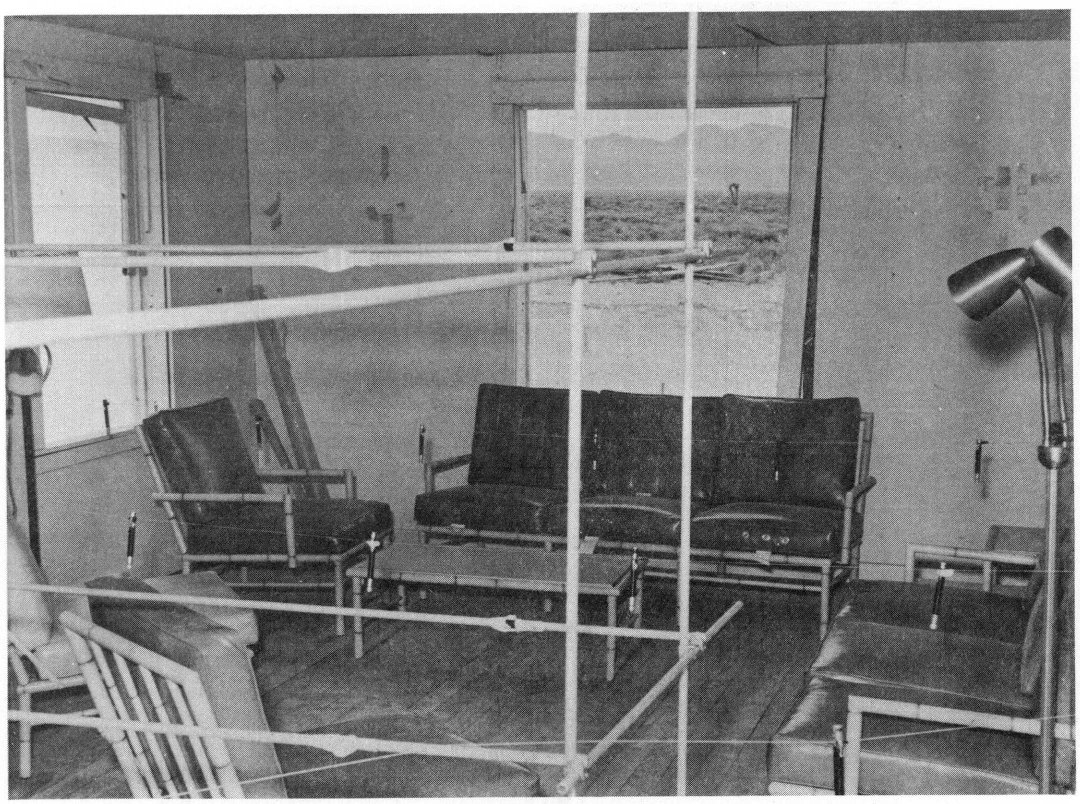


(b)

Fig. 2.26 — PCC house with living-room openings (exterior) filled with concrete blocks.

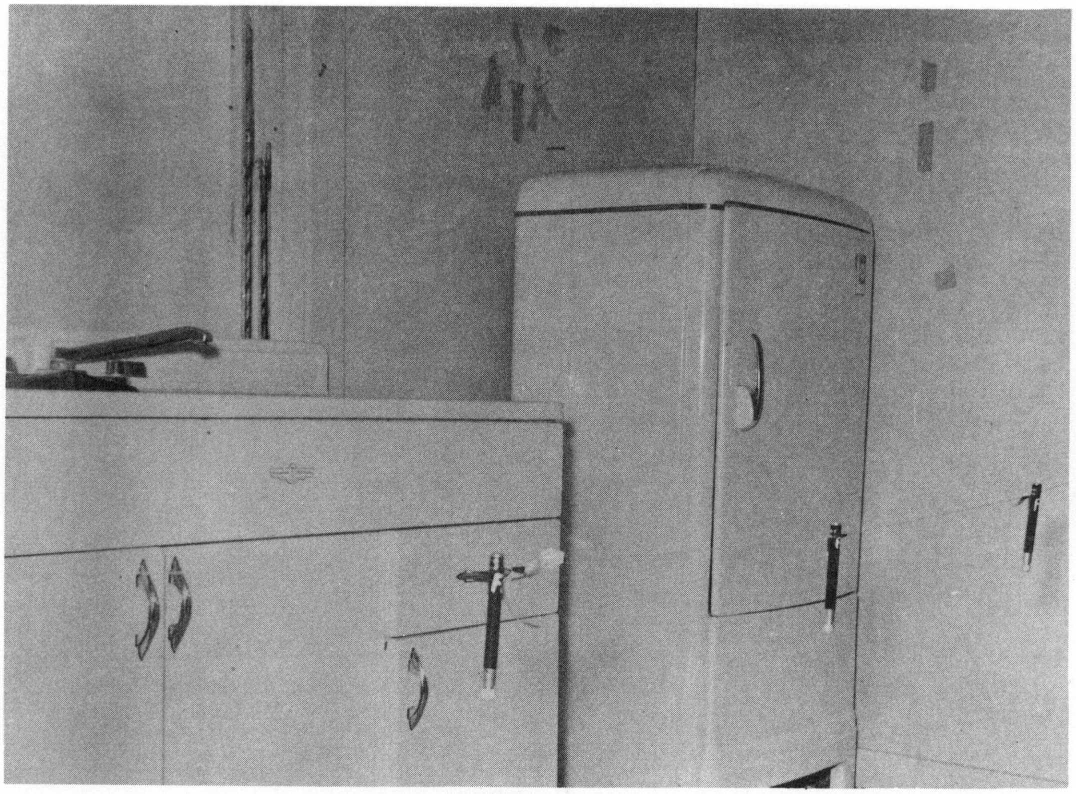


(a)



(b)

Fig. 2.27—Interior of the 2SWF house with some furniture.



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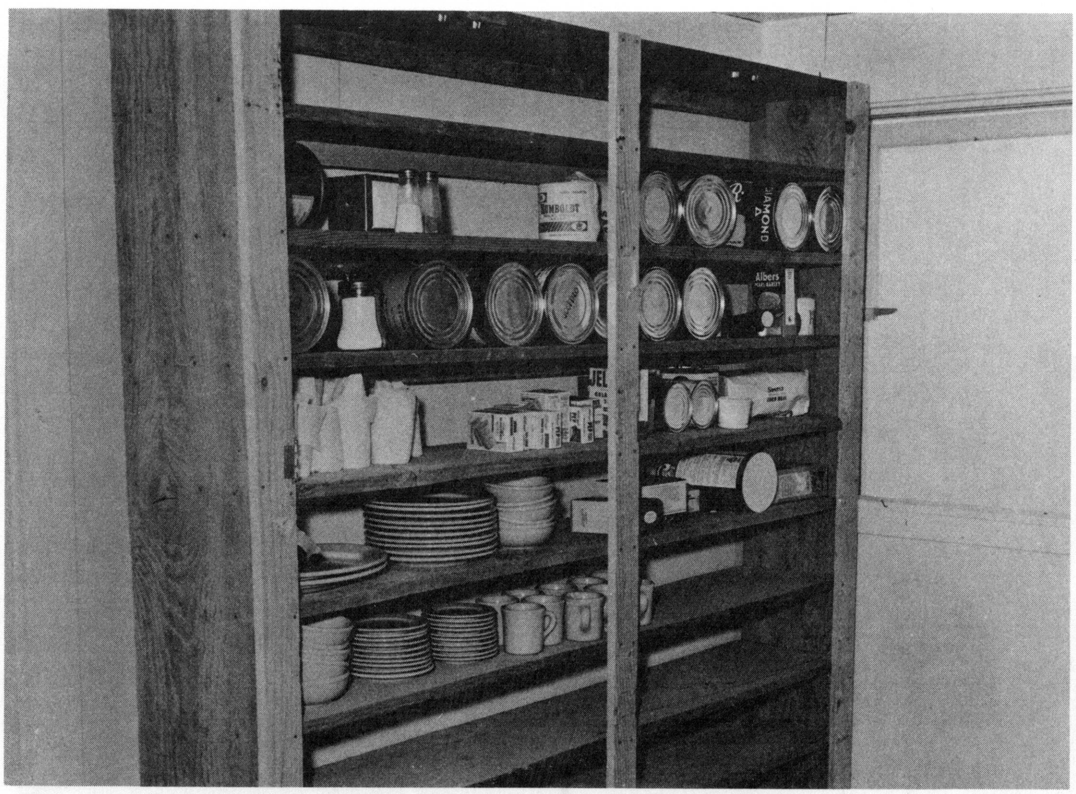

(b)

Fig. 2.28—Interior of the 2SWF house with some furniture and supplies.

Fig. 2.29—Interior of the 2SWF house.

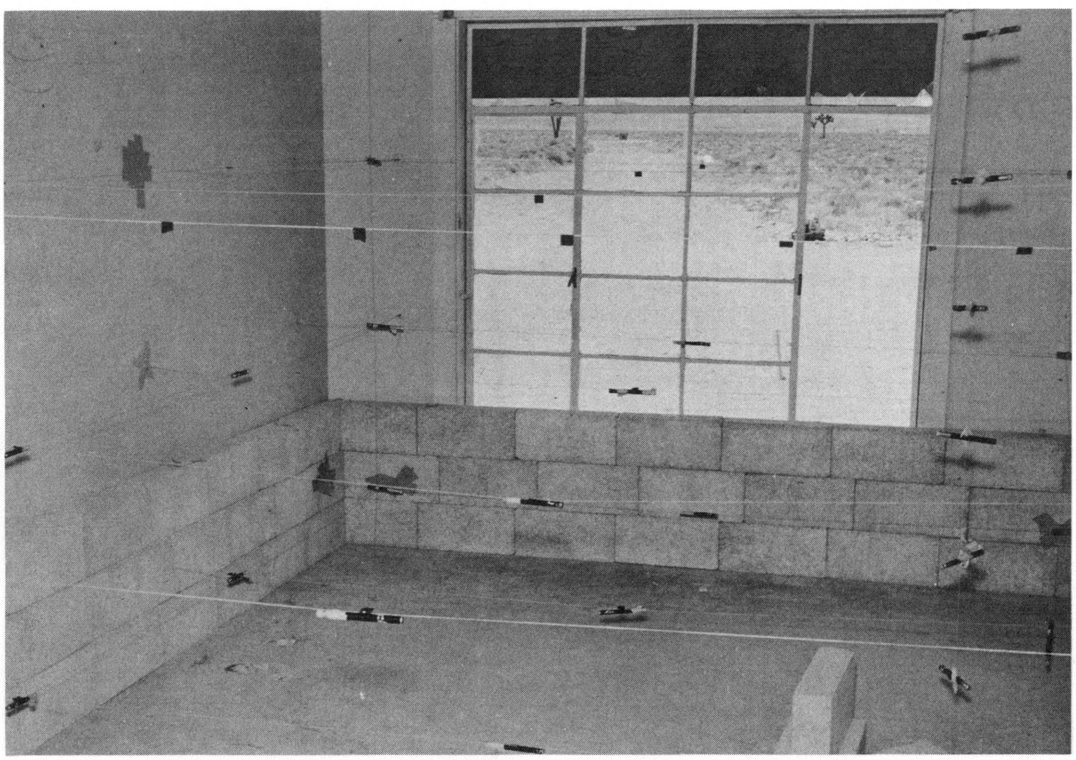

Fig. 2.30—Interior of the rambler house with 24-in.-high concrete-block wall.

2.4.10 Modifications

The modifications that a home owner could make to his home to increase the protection against radioactive fallout which it would afford could be of the utmost importance to the survival of his family. Some of these modifications made to the structures studied were as follows:

1. Basement window wells were filled with sandbags, and sandbags were stacked in front of these windows. Figure 2.21 shows a window well prior to the experiment; Fig. 2.22 shows a similar well with sandbags in place; and Fig. 2.23 is an inside view of the same window with the bags in place.

2. Tables were placed in the basements and covered with two layers ($7\frac{1}{4}$ in. high) concrete blocks, as shown in Fig. 2.24. The concrete blocks used were solid concrete (density, 150 lb/cu ft), measuring $15\frac{1}{2}$ by $7\frac{1}{2}$ by $3\frac{5}{8}$ in.

3. The wooden shelter in the basement of the two-story frame house was covered with two layers of concrete blocks ($7\frac{1}{4}$ in. high), as shown in Fig. 2.25.

4. Concrete blocks (one layer, $3\frac{5}{8}$ in. thick) were placed over the window and door of the living room of the precast concrete house, as shown in Fig. 2.26. Modification of one room was sufficient since the inner walls were all of poured concrete.

5. Since the measurements were made in nonfurnished houses, furniture was placed in the two-story frame house to determine the shielding such furniture affords. Furniture effects would, in general, be negligible in heavy-walled houses. The arrangement of furniture, supplies, and fixtures is depicted in Figs. 2.27 to 2.29.

6. Concrete blocks were placed around the inside of the exterior walls of the dining-living area of the wood rambler. The thickness of concrete was $3\frac{5}{8}$ in. This arrangement is shown in Fig. 2.30.

REFERENCE

1. F. H. Day, X-ray Calibration of Radiation Survey Meters, Pocket Chambers and Dosimeters, Report RA-DET-3-4, April 1950.

Chapter 3

PRESENTATION OF DATA

3.1 GENERAL

A brief description of the experiments and some of the exposure parameters are given in Table 3.1.

The usual levels for horizontal traverses were 3 and 5 ft above the floor. At key points the number of levels was increased to establish vertical traverses. The bulk of the data are presented on house floor plans, with the positions of the vertical traverses indicated by letters. The dose rates for the vertical traverses are given in tables; the table for a given exposure immediately follows the horizontal traverse data. Figure 3.1 shows the code for the key positions at which vertical traverses were most often made. The dose rates reported are normalized as follows: for ring sources, mr/hr/4-millicurie source/2 ft; for other distributed sources, mr/hr/millicurie/sq ft; and for point sources, mr/hr/curie.

3.1.1 Phantom House Dose-rate Distributions (Distributed Co^{60} Sources)

The horizontal dose-rate distributions in the phantom house for the 3-, 5-, and 11.5-ft levels for sources distributed on the floor on 2- by 2-ft centers are given in Figs. 3.2, 3.3, and 3.4, respectively. The vertical traverse dose rates are given in Table 3.2.

The horizontal dose-rate distributions for the 3-, 5-, and 11.5-ft levels for a ring of sources of 25.5 ft radius about the center of the house (ρ = 25.5 ft) are given in Figs. 3.5, 3.6, and 3.7, respectively. The vertical traverse dose rates are given in Table 3.3.

The horizontal dose-rate distributions for the 3-, 5-, and 11.5-ft levels for ρ = 31.8 ft are given in Figs. 3.8, 3.9, and 3.10, respectively. The vertical traverse dose rates are given in Table 3.4.

The horizontal dose-rate distributions for the 3-, 5-, and 11.5-ft levels for ρ = 42.5 ft are given in Figs. 3.11, 3.12, and 3.13, respectively. The vertical traverse dose rates are given in Table 3.5.

The horizontal dose-rate distribution for the 5-ft level for ρ = 63.7 ft is given in Fig. 3.14. The vertical traverse dose rates are given in Table 3.6.

The horizontal dose-rate distributions for the 3- and 5-ft levels for ρ = 127 ft are given in Figs. 3.15 and 3.16, respectively. The vertical traverse dose rates are given in Table 3.7.

3.1.2 Two-story Wood Frame (2SWF) House Dose-rate Distributions

The horizontal dose-rate distributions in the 2SWF house at 3 ft in the basement, at 1, 3, and 5 ft on the first floor, and at 3 ft on the second floor for ρ = 21.2 ft are given in Figs. 3.17, 3.18, 3.19, 3.20, and 3.21, respectively. The vertical traverse dose rates are given in Tables 3.8 and 3.9 for the basement and the first floor, respectively.

The horizontal dose-rate distributions for the 3-ft level in the basement, on the first floor, and on the second floor for ρ = 25.5 ft are given in Figs. 3.22, 3.23, and 3.24, respectively. The vertical traverse dose rates are given in Tables 3.10, 3.11, and 3.12, respectively.

The horizontal dose-rate distributions for the 3-ft level in the basement, on the first floor, and on the second floor for $\rho = 31.8$ ft are given in Figs. 3.25, 3.26, and 3.27, respectively. The vertical traverse dose rates are given in Tables 3.13 to 3.15.

The preceding exposure, $\rho = 31.8$ ft, was repeated with some furniture in the house (see Sec. 2.4.10). The horizontal dose-rate distributions for this exposure for levels at 3 and 6.5 ft in the basement and for the 3-ft level on the first and second floors are given in Figs. 3.28, 3.29, 3.30, and 3.31, respectively. The vertical traverse dose rates are given in Tables 3.16 to 3.18.

The horizontal dose-rate distributions for the 3-ft level in the basement on the first floor, and on the second floor for $\rho = 42.5$ ft are given in Figs. 3.32, 3.33, and 3.34, respectively. The vertical traverse dose rates are given in Tables 3.19 to 3.21.

The horizontal dose-rate distributions for the 3-ft level in the basement, on the first floor, and on the second floor for $\rho = 63.7$ ft are given in Figs. 3.35, 3.36, and 3.37, respectively. The vertical traverse dose rates are given in Tables 3.22 to 3.24.

Sources were distributed uniformly in the area between the house and the innermost source ring ($\rho = 21.2$ ft). The horizontal dose-rate distributions for the 3-ft level in the basement, on the first floor, and on the second floor for this source arrangement are given in Figs. 3.38, 3.39, and 3.40, respectively. The vertical traverse dose rates are given in Tables 3.25 to 3.27 for this fill-in exposure.

With sources distributed uniformly over the west half of the roof, the dose rates were measured throughout the house. The horizontal dose-rate distributions for the 3-ft levels in the basement, on the first floor, and on the second floor for this source array are given in Figs. 3.41, 3.42, and 3.43, respectively. The vertical traverse dose rates are given in Tables 3.28 to 3.30.

The horizontal dose-rate distributions for the 3-ft level in the basement, on the first floor, and on the second floor for sources distributed over the entire roof area are shown in Figs. 3.44, 3.45, and 3.46, respectively. The vertical traverse dose rates are given in Tables 3.31 to 3.33. These measurements were for a house devoid of furniture.

A second full-roof exposure was made with some furniture and supplies in the house (see Sec. 2.4.10). The horizontal dose-rate distributions for the 3- and 6.5-ft levels in the basement and for the 3-ft level on the first and second floors are given in Figs. 3.47, 3.48, 3.49, and 3.50, respectively. The vertical traverse dose rates are given in Tables 3.34 to 3.36.

One exposure was made with strings of sources in the roof gutter on the east side of the house. The horizontal dose-rate distributions at the 5-ft level in the basement, on the first floor, and on the second floor are given in Figs. 3.51, 3.52, and 3.53, respectively. The sandbags were removed from the four southernmost basement windows before this exposure.

3.1.3 Precast Concrete (PCC) House Dose-rate Distributions

The horizontal dose-rate distributions for the PCC house for the 3- and 5-ft levels are presented in Figs. 3.54 and 3.55, respectively, for $\rho = 25.5$ ft. The vertical traverse dose rates are given in Table 3.37.

The horizontal dose-rate distributions for the 3-, 5-, and 7-ft levels for $\rho = 42.5$ ft are given in Figs. 3.56, 3.57, and 3.58, respectively. The exterior openings in the living room were closed with concrete blocks (see Sec. 2.4.10). The horizontal dose-rate distributions for the 3- and 5-ft levels for $\rho = 42.5$ ft with this modification are given in Figs. 3.59 and 3.60, respectively. The vertical traverse dose rates are given in Table 3.38.

Sources were distributed uniformly on the roof on 2-ft centers. The horizontal dose-rate distributions at the 3- and 5-ft levels are given in Figs. 3.61 and 3.62, respectively. The vertical traverse dose rates are given in Table 3.39.

Sources were placed on the roof over the northwest bedroom only for one exposure. They were on 2-ft centers in a 6- by 8-ft array, the longer dimension being aligned with the longer dimension of the room and the geometrical center of the array being over that of the room. The horizontal dose-rate distributions for the 1-, 3-, and 5-ft levels are shown in Figs. 3.63, 3.64, and 3.65, respectively. The 5-ft level has a traverse extending through the north window over the lawn for a distance of 10 ft.

3.1.4 Wood Rambler (WR) House Dose-rate Distributions

The horizontal dose-rate distributions for the rambler house for the 3- and 5-ft levels are given in Figs. 3.66 and 3.67, respectively, for ρ = 25.5 ft. The vertical traverse dose rates are given in Table 3.40.

The horizontal dose-rate distributions for the 3- and 5-ft levels for ρ = 42.5 ft are given in Figs. 3.68 and 3.69, respectively. The vertical traverse dose rates are given in Table 3.41.

A uniform distribution of sources on 2-ft centers was placed over the entire roof area. The horizontal dose-rate distributions for the 3- and 5-ft levels are given in Figs. 3.70 and 3.71. The vertical traverse dose rates are given in Table 3.42.

3.1.5 Two-story Brick (2SB) House Dose-rate Distributions

The horizontal dose-rate distributions for the 2SB house for the 3- and 5-ft levels in the basement and for the 3- and 5-ft levels on the first floor are given in Figs. 3.72, 3.73, 3.74, and 3.75, respectively, for ρ = 25.5 ft. There were sandbags in the four southernmost basement window wells and over the associated windows. A table covered with $7\frac{1}{4}$-in. thickness of concrete blocks was in the southeast corner of the basement. The vertical traverse dose rates are given in Tables 3.43 and 3.44.

The horizontal dose-rate distributions for the 3- and 5-ft levels in the basement and the 3- and 5-ft levels on the first floor for ρ = 42.5 ft are given in Figs. 3.76, 3.77, 3.78, and 3.79, respectively. The position of the sandbags and concrete blocks was the same as that for the exposure at ρ = 25.5 ft. The vertical traverse dose rates are given in Tables 3.45 and 3.46.

3.1.6 Reinforced-concrete-block (RCB) House Attenuation Study

Attenuation measurements were made with a single Co^{60} source and a survey type ionization chamber. The large and abrupt changes in transmission are indicated in Fig. 3.80, which is a diagram of the geometrical arrangement and relative readings. The source was placed 4 ft from the north wall, 3 ft from the east wall, and 47 in. above the floor. The other positions are drawn to the same scale.

3.2 RECIPROCITY

Point-source measurements were made with Co^{60} and Cs^{137} sources. Only the Co^{60} exposures are reported here, but it is evident that the Cs^{137} data in Sec. 3.3 can be analyzed for reciprocity applicability. All readings, except those made with the survey instrument, have been normalized to milliroentgens per hour per curie. PIC's were placed at points on the ground rings of various radii used for the extended sources and at points on the roof surface.

3.2.1 Two-story Wood Frame (2SWF) House

With the 2.1-curie Co^{60} source positioned 3 ft above the center of the first floor, the dose-rate distribution was measured and is shown in Fig. 3.81.

An exposure was also made with the Co^{60} source 3 ft above the center of the second floor. The dose-rate distribution on the ground and on the roof is given in Fig. 3.82.

The 2.1-curie Co^{60} source was also placed in the north area of the basement of the 2SWF house. It was 3 ft above the floor, centered under the peak of the roof, and on a line connecting the centers of the northernmost east and west basement windows. Figure 3.83 shows the dose-rate distribution for this placement.

A source placement was also made on the first floor at a point 1 ft from the north end at the north-south center line of the house. The Co^{60} source was 3 ft above the floor. Dose rates as a function of position on the ground and roof are shown in Fig. 3.84.

Two exposures were made at the 2SWF house with the small standard calibration source (8.4-millicurie Co^{60}). A G-M survey instrument was used for the measurements that were made with the intent of exploring the feasibility of sensitive-energy-dependent detectors. The response of the instrument as a function of position is given in Figs. 3.85, 3.86, and 3.87 for the basement, first floor, and second floor, respectively, for a source location 3 ft above the first floor at the center of the house. Figures 3.88, 3.89, 3.90, and 3.91 show the response for the basement, first floor, second floor, and roof, respectively, for a source location 3 ft above the second floor. All measurements inside the house were made 3 ft above the floor, and those made outside were made at approximately 1 in. above the ground or roof.

3.2.2 Precast Concrete (PCC) House

The 2.1-curie Co^{60} source was placed 3 ft above the floor at a point near the center of the house. The dose-rate distribution on the ground and roof for this source position is shown in Fig. 3.92.

A source placement was made in the center of the northwest bedroom at a height of 3 ft above the floor. The dose-rate distribution for this exposure is shown in Fig. 3.93.

The 2.1-curie source was also placed on the roof of the PCC house at a point 2 ft east and 4 ft south of the center of the northwest bedroom. The position of the source and the dose rate at the point occupied by the source in Fig. 3.93 are shown in Fig. 3.94.

3.2.3 Air Scatter

The only data obtained for the skyshine exposure described in Sec. 2.4.8 are presented in Fig. 3.95 for a source position 3 ft below ground level and on the vertical axis of the hole.

3.3 ENERGY DEPENDENCE

The Cs^{137} sources were used for a limited number of exposures for checking energy dependence. The PIC's were placed outside as they were in Sec. 3.2.

3.3.1 Two-story Wood Frame (2SWF) House

The 1.82-curie Cs^{137} source was placed 3 ft above the center of the first floor of the house, and measurements were made on the ground and roof. The dose-rate distribution is shown in Fig. 3.96.

An exposure was also made with the Cs^{137} source positioned 3 ft above the center of the second floor. Figure 3.97 shows the dose-rate distribution for this placement.

3.3.2 Precast Concrete (PCC) House

Nineteen of the small (23-millicurie) Cs^{137} sources were distributed uniformly on the roof, and the dose-rate distribution was measured inside the house (Fig. 3.98). The array consisted of four east-west columns of five sources each (except for the front column, which terminated near the offset in the roof and contained only four sources). This array was centered on the roof with the columns 8 ft apart and a separation along the column of 8.5 ft. The vertical traverse dose rates are given in Table 3.47.

The 20 Cs^{137} sources of 23 millicuries each were placed in a 4- by 5-source array on 2-ft centers, and the array was centered over the northwest bedroom of the PCC house in the same manner as the Co^{60} sources that were used for the data in Figs. 3.63 to 3.65 (see Sec. 3.1.3). The horizontal dose-rate distributions for the cesium exposure are given in Figs. 3.99 and 3.100 for the 3- and 5-ft levels, respectively. The vertical traverse dose rates are given in Table 3.48.

TABLE 3.1—EXPOSURE PARAMETERS

Exposure No.	House	ρ, ft	n*	Description	Sources	Remarks
1	2SWF	21.2	6	Ground	400 Co^{60}	
2	2SWF	63.7	2	Ground	400 Co^{60}	
3	2SWF	25.5	5	Ground	400 Co^{60}	
4	Phant.			Floor	172 Co^{60}	Deposited uniformly on area the size of 2SWF and 2SB houses
5	Phant.	~42.5	3	Ground	120 Co^{60}	
6	2SWF	Fill-in		Fill-in	112 Co^{60}	Sixteen at each end; 40 at each side
7	Phant.	25.5	5	Ground	160 Co^{60}	
8	Phant.	31.8	4	Ground	200 Co^{60}	
9	2SWF†	31.8	4	Ground	200 Co^{60}	
10	2SWF†	42.5	3	Ground	399 Co^{60}	
11	2SWF†			Half-roof	100 Co^{60}	
12	2SWF†			Full-roof	200 Co^{60}	
13	PCC			Full-roof	19 Cs^{137}	
14	2SWF†			Full-roof	197 Co^{60}	Furniture
15	2SWF†	31.8	4	Ground	399 Co^{60}	Furniture
16	2SWF†			Reciprocity	2-curie Co^{60}	Furniture; 3 ft, second floor center
17	Phant.	63.7	2	Ground	399 Co^{60}	
18	PCC	25.5	5	Ground	380 Co^{60}	
19	2SWF†			Reciprocity	2-curie Co^{60}	3 ft above first floor, center of house
20	PCC	42.5	3	Ground	380 Co^{60}	
21	PCC			Roof	40 Co^{60}	NW bedroom only; 2-ft centers
22	2SWF†			Reciprocity	2-curie Co^{60}	Center of N half of basement, 3 ft above floor
23	PCC			Full-roof	310 Co^{60}	
24	2SWF†			Reciprocity	2-curie Cs^{137}	3 ft above first floor, center of house
25	PCC			Roof	20 each 23-millicurie Cs^{137}	NW bedroom only; 2-ft centers
26	2SWF†			Reciprocity	2-curie Cs^{137}	3 ft above second floor, center of house
27	WR	25.5	5	Ground	389 Co^{60}	
28	PCC			Reciprocity	2-curie Co^{60}	3 ft high, center of house
29	PCC	42.5	3	Ground	399 Co^{60}	Exterior door and window filled with $3\frac{5}{8}$-in.-thick concrete blocks
30	2SWF†			Reciprocity	2-curie Co^{60}	Center of N end, 1 ft from wall
31	WR	42.5	3	Ground	380 Co^{60}	Concrete blocks around outside wall of living-dining area
32	WR			Full-roof	293 Co^{60}	Concrete blocks around outside wall of living-dining area
33	PCC			Reciprocity	2-curie Co^{60}	3 ft high, center; NW bedroom
34	PCC			Reciprocity	2-curie Co^{60}	2 ft E and 4 ft S of center; NW bedroom
35	2SB	25.5	5	Ground	379 Co^{60}	Sandbags in four southernmost basement windows; tables with concrete blocks in SW corner
36	Hole			Skyshine	2-curie Co^{60}	3 ft down hole, 2 ft wide by 6 ft deep
37	2SB	42.5	3	Ground	380 Co^{60}	Sandbags in four southernmost basement windows
38	2SWF			Gutter	200 Co^{60}	Folded to 32-ft lengths
39	RMB					Poor slab geometry
40	Phant.	127	1	Ground	399 Co^{60}	
41	2SWF†	21.2	6		Co^{60} calib. source	Survey meter used inside and outside house

*n, number of turns (see Table 2.2).

†Two tables and the NW shelter in the basement were covered with concrete blocks, and there were sandbags in the four southernmost basement windows.

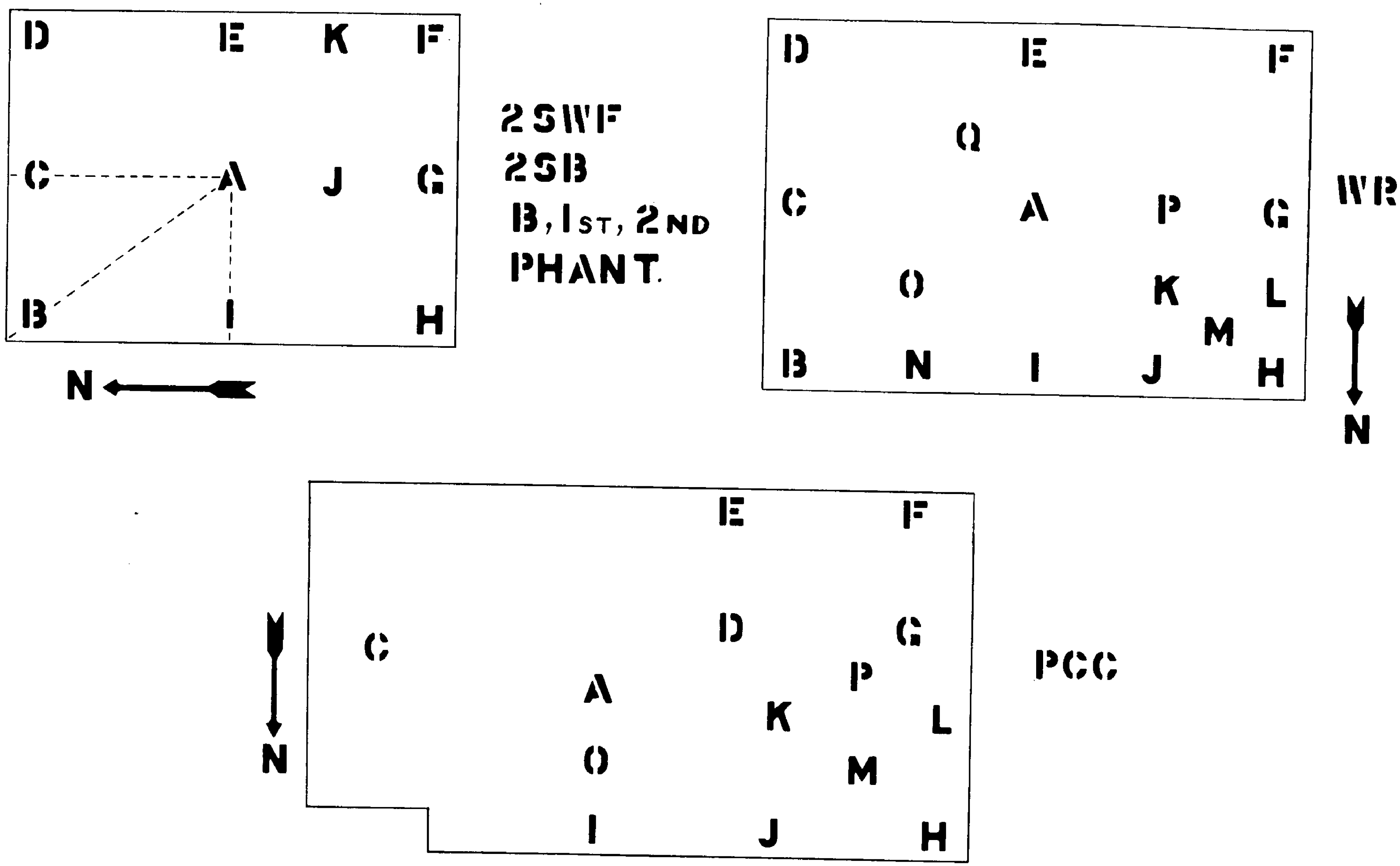

Fig. 3.1—General vertical traverse codes for all houses.

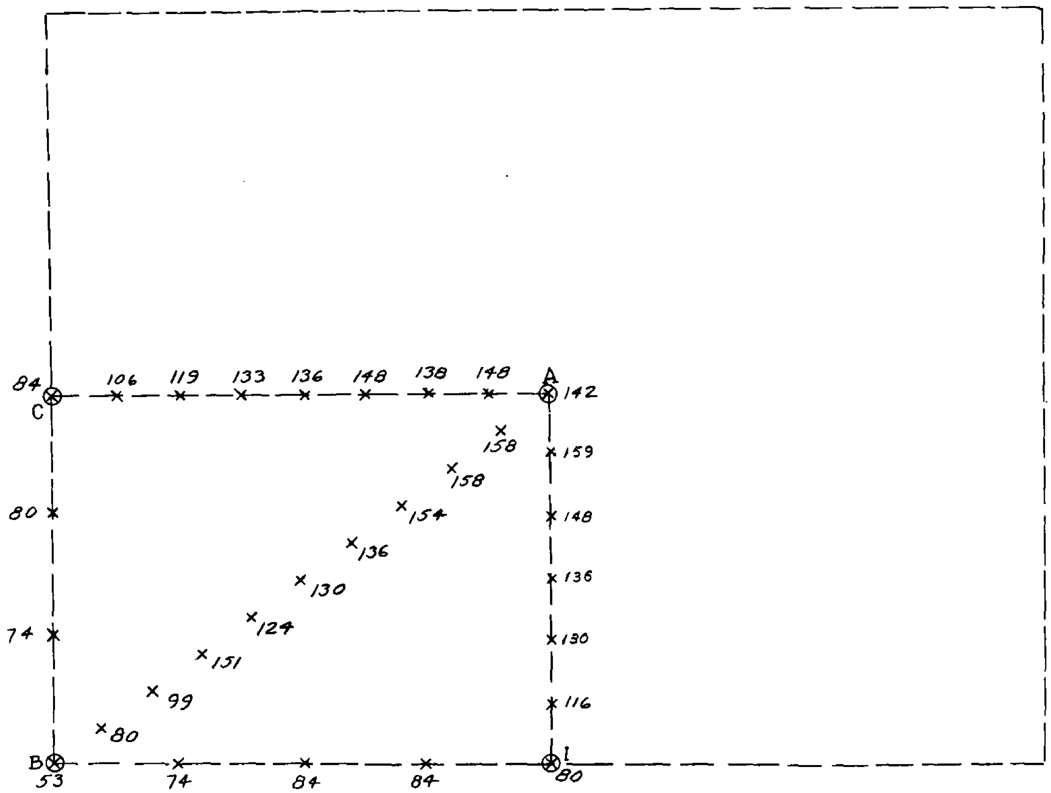

Fig. 3.2—Phantom house, 3-ft level, sources distributed on floor.

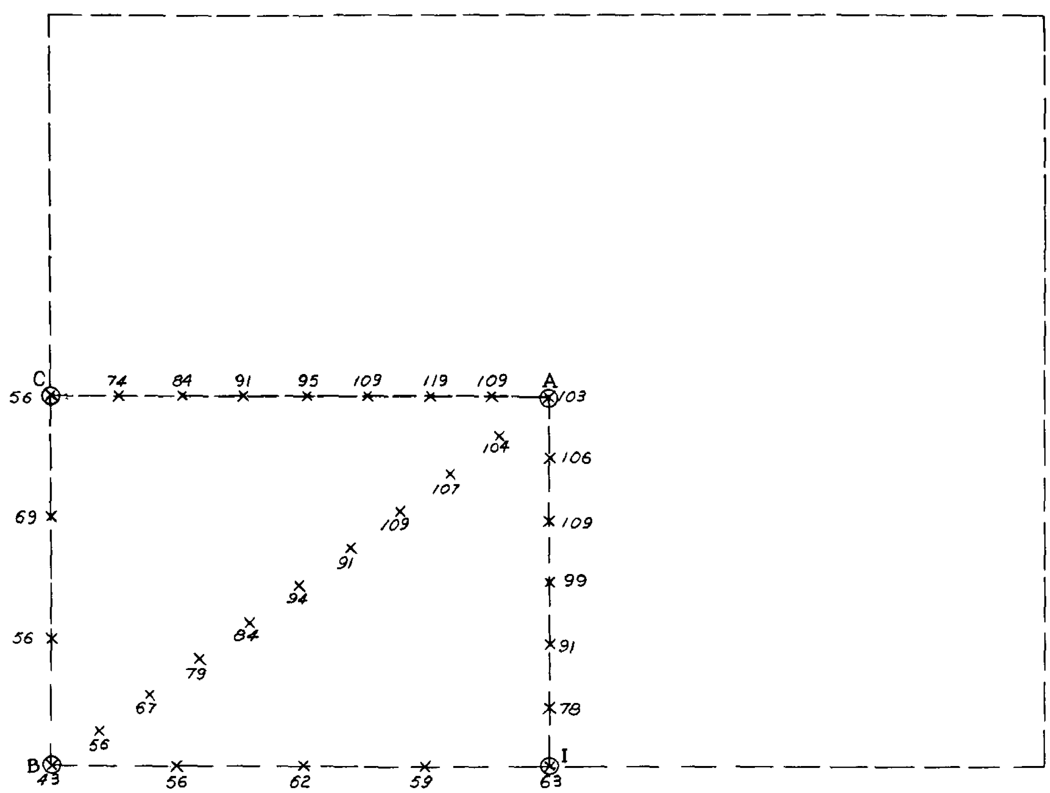

Fig. 3.3—Phantom house, 5-ft level, sources distributed on floor.

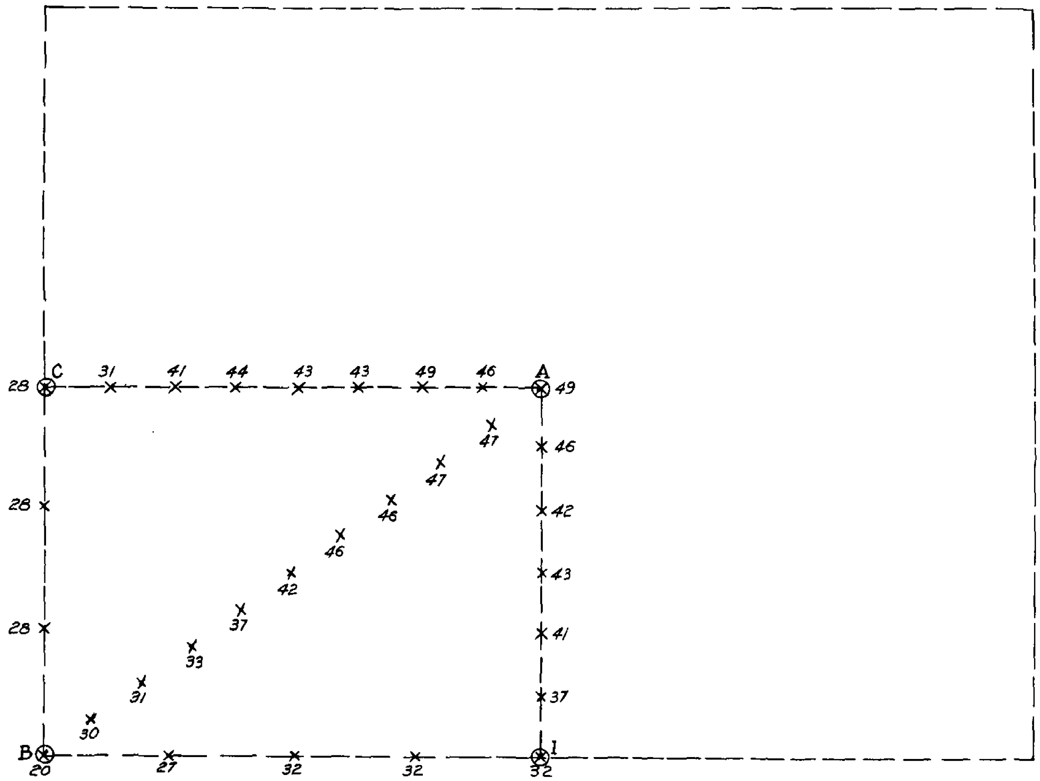

Fig. 3.4—Phantom house, 11.5-ft level, sources distributed on floor.

TABLE 3.2—VERTICAL TRAVERSES FOR THE PHANTOM HOUSE FOR SOURCES DISTRIBUTED ON THE FLOOR

Position	3 ft	5 ft	7 ft	9 ft	11.5 ft	13 ft	15 ft
A	142	103	78	62	49	37	30
B	53	43	37	28	20	19	16
C	84	56	46	40	28	25	31
I	80	63	49	41	32	25	25

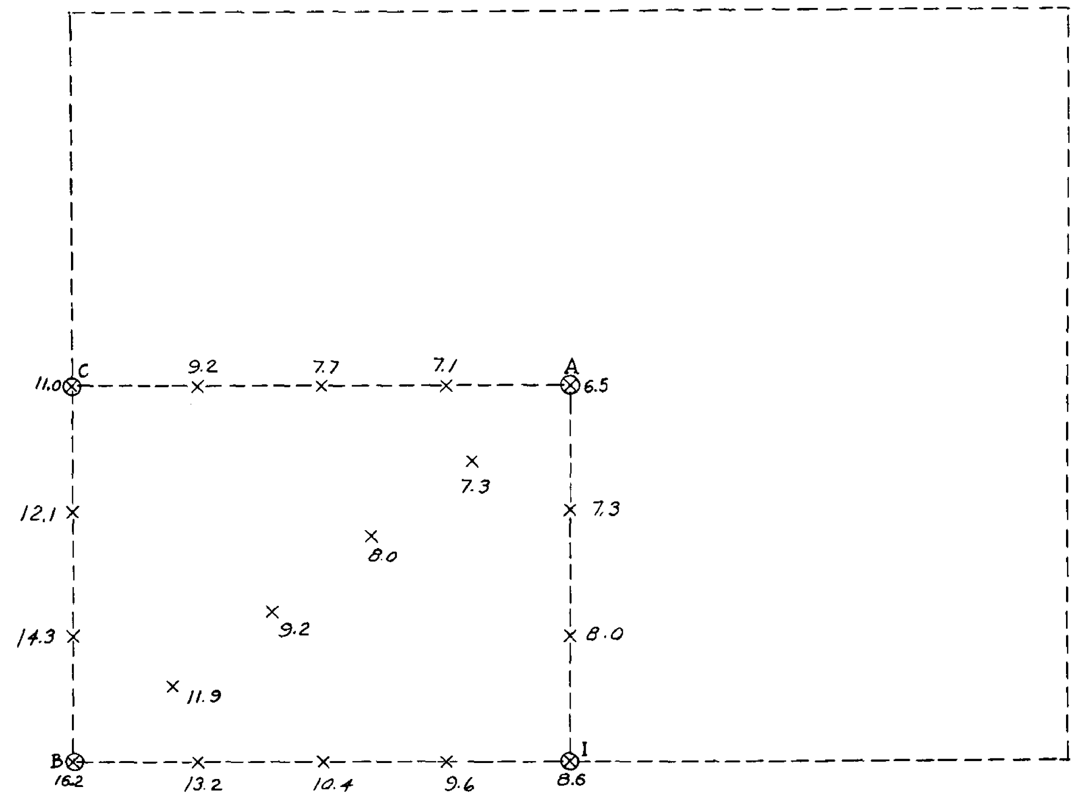

Fig. 3.5 — Phantom house, 3-ft level, ρ = 25.5 ft.

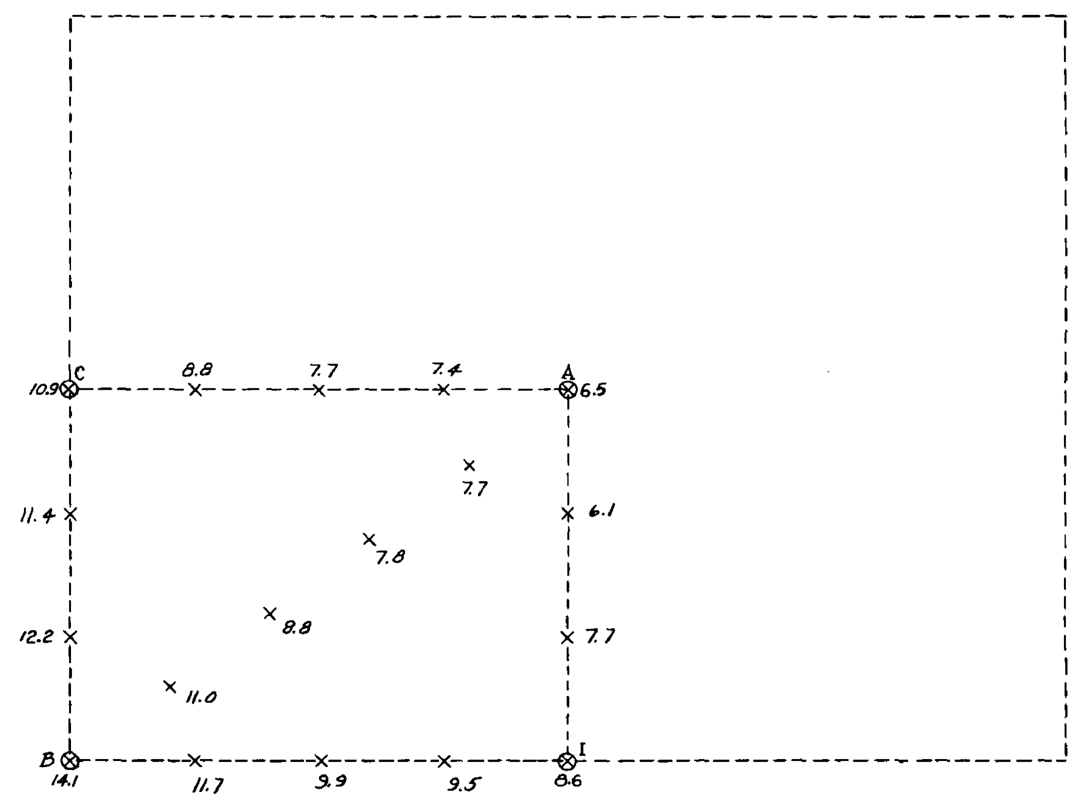

Fig. 3.6 — Phantom house, 5-ft level, ρ = 25.5 ft.

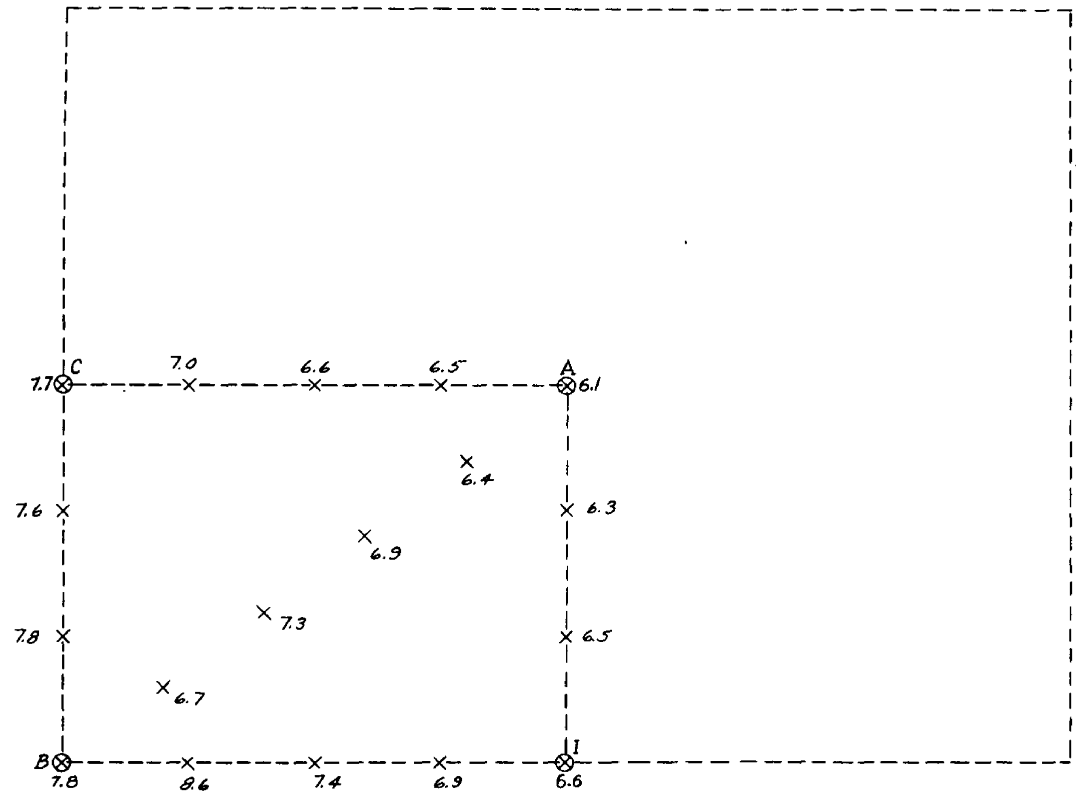

Fig. 3.7—Phantom house, 11.5-ft level, ρ = 25.5 ft.

TABLE 3.3—VERTICAL TRAVERSES FOR THE PHANTOM HOUSE FOR ρ = 25.5 FT

Position	3 ft	5 ft	7 ft	9 ft	11.5 ft	13 ft	15 ft
A	6.5	6.5	6.6	6.1	6.1	5.5	5.0
	16.2	14.1	12.0	10.2	7.8	7.4	6.3
	11.0	10.9	9.9	8.8	7.7	7.1	6.5
	8.6	8.6	7.8	7.4	6.6	5.8	5.8

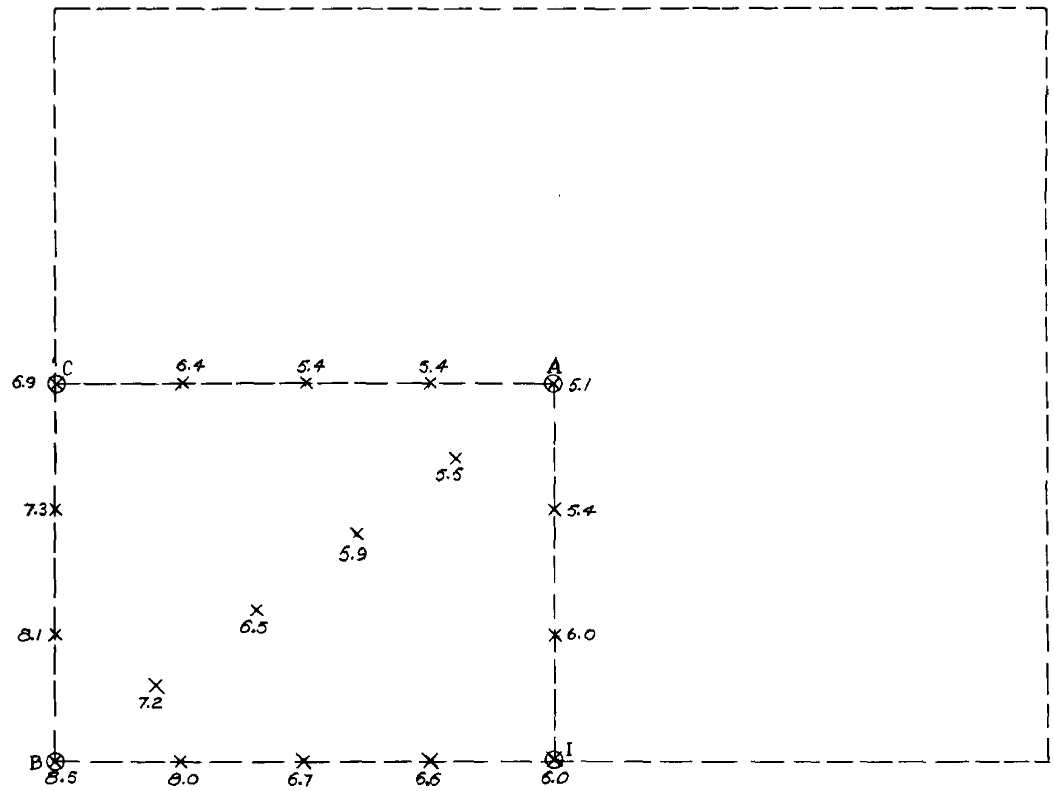

Fig. 3.8 — Phantom house, 3-ft level, ρ = 31.8 ft.

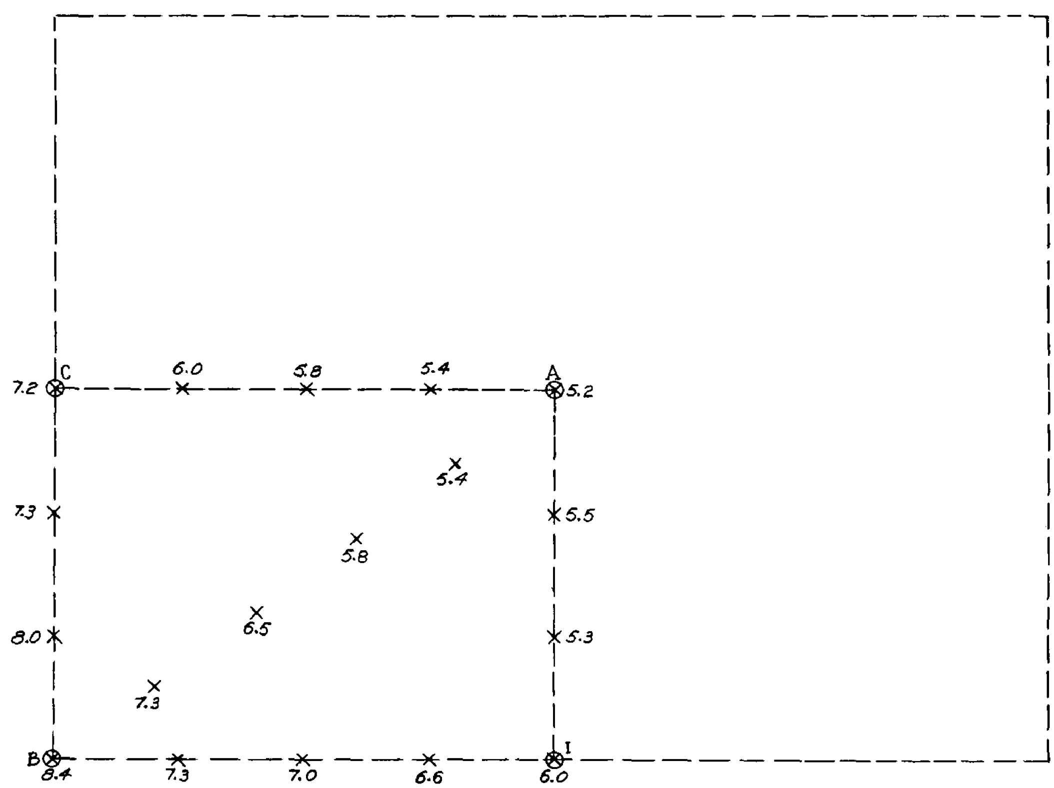

Fig. 3.9 — Phantom house, 5-ft level, ρ = 31.8 ft.

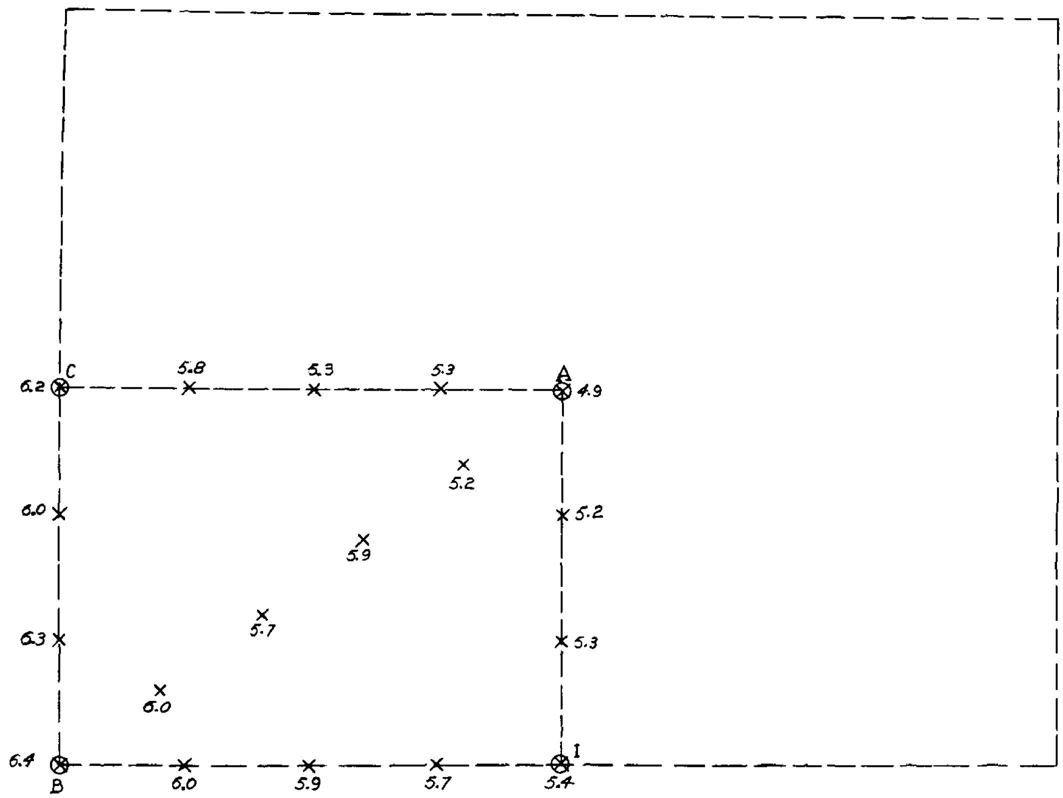

Fig. 3.10—Phantom house, 11.5-ft level, ρ = 31.8 ft.

TABLE 3.4—VERTICAL TRAVERSES FOR THE PHANTOM HOUSE FOR ρ = 31.8 FT

Position	3 ft	5 ft	7 ft	9 ft	11.5 ft	13 ft	15 ft
A	5.1	5.2	5.2	4.8	4.9	4.6	4.5
B	8.5	8.4	8.0	7.4	6.4	6.0	5.6
C	6.9	7.2	6.9	6.6	6.2	5.8	5.4
I	6.0	6.0	6.0	5.8	5.4	5.0	4.6

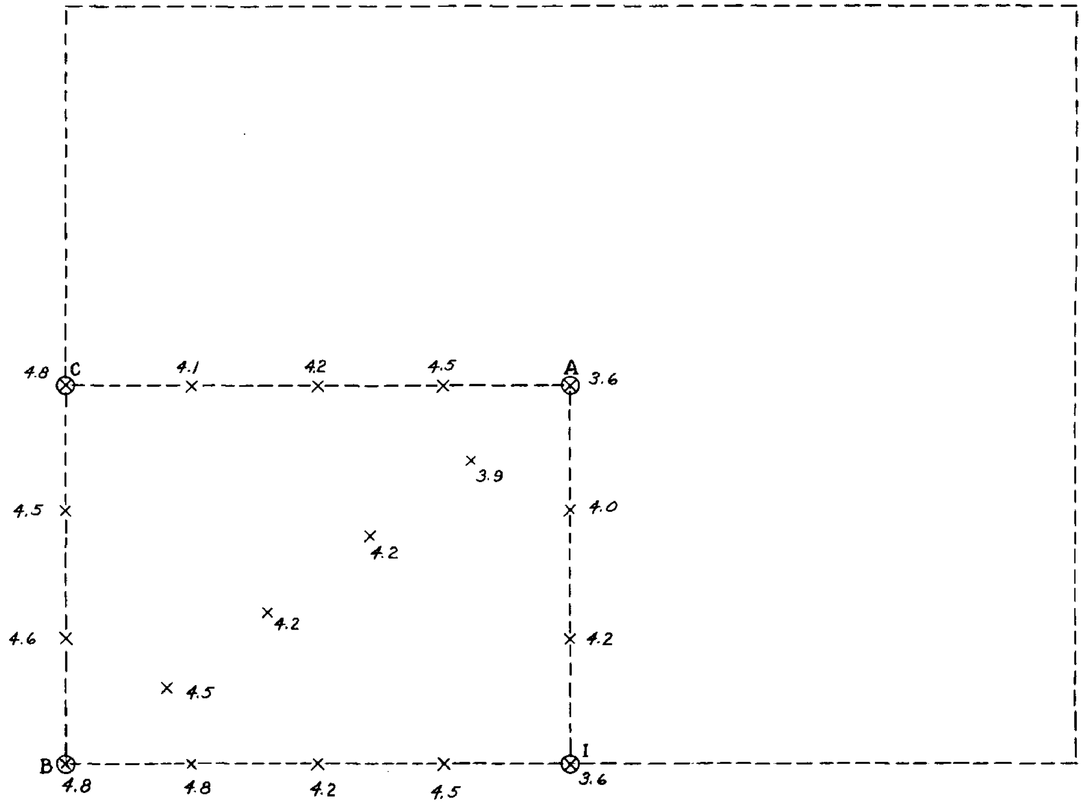

Fig. 3.11—Phantom house, 3-ft level, ρ = 42.5 ft.

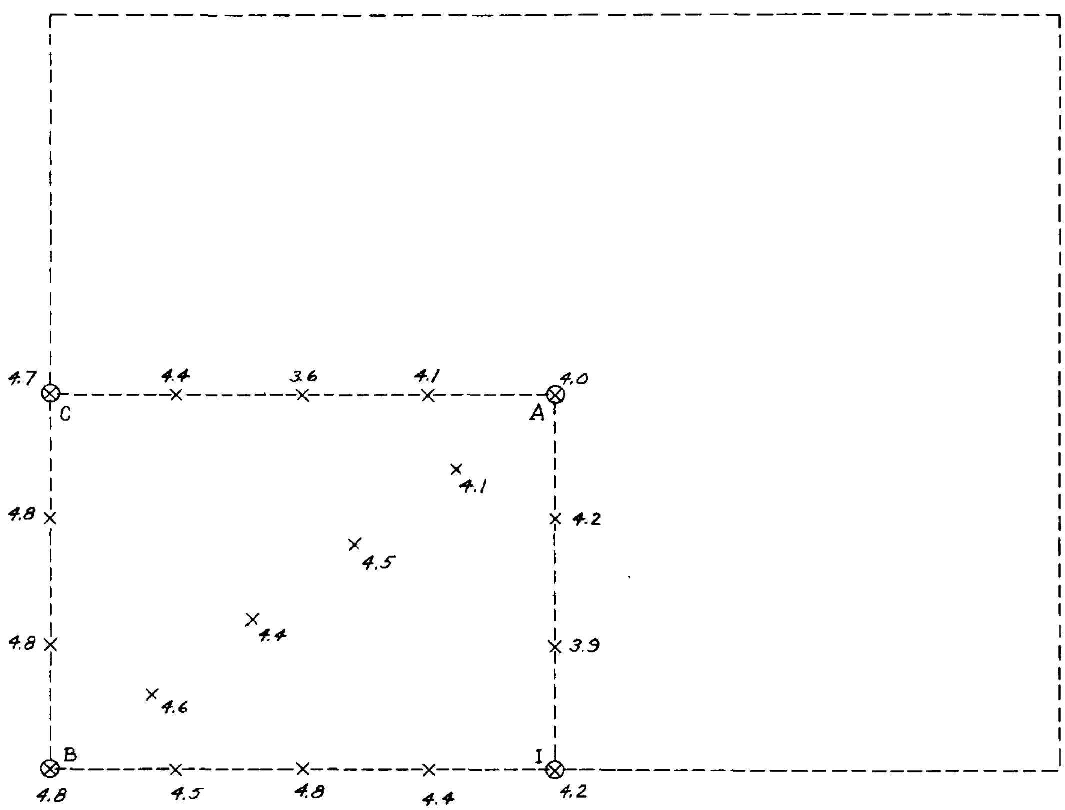

Fig. 3.12—Phantom house, 5-ft level, ρ = 42.5 ft.

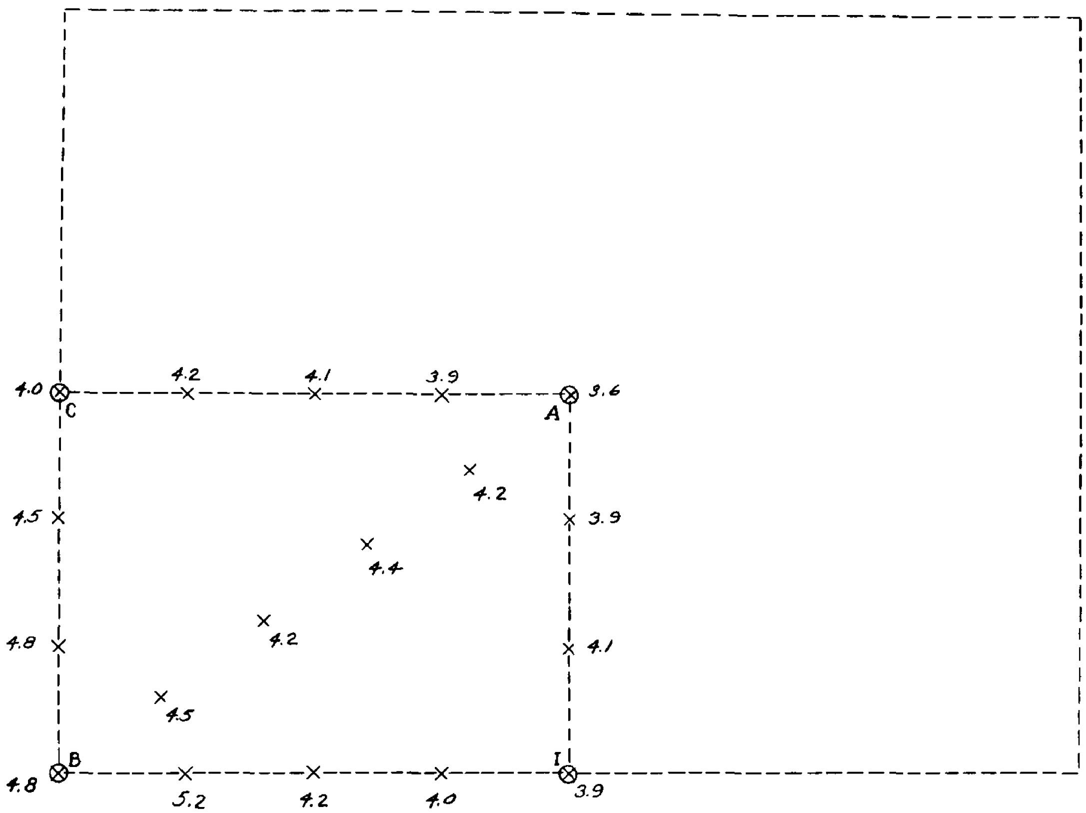

Fig. 3.13—Phantom house, 11.5-ft level, $\rho = 42.5$ ft.

TABLE 3.5—VERTICAL TRAVERSES FOR THE PHANTOM HOUSE FOR $\rho = 42.5$ FT

Position	3 ft	5 ft	7 ft	9 ft	11.5 ft	13 ft	15 ft
A	3.9	4.0	4.2	4.2	3.6	3.6	3.6
B	4.8	4.8	4.8	4.8	4.8	4.8	4.5
C	4.8	4.7	4.8	4.6	4.0	4.7	4.5
I	3.6	4.2	4.2	4.4	3.9	4.2	3.8

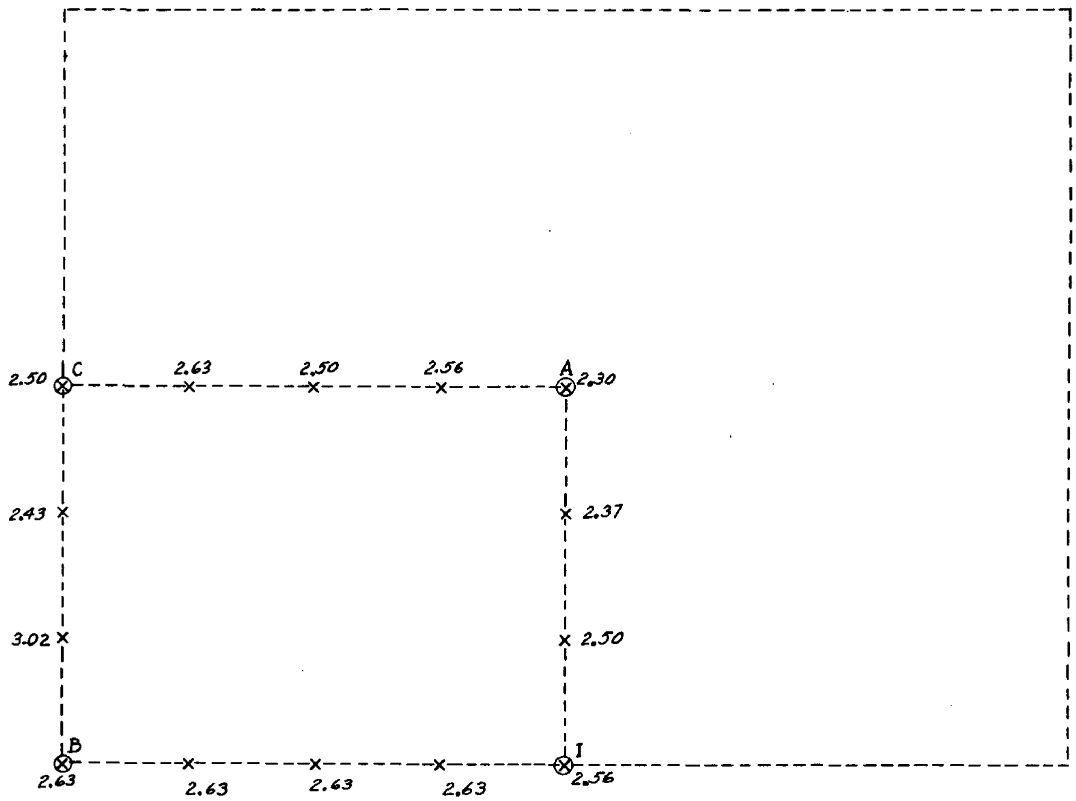

Fig. 3.14—Phantom house, 5-ft level, ρ = 63.7 ft.

TABLE 3.6—VERTICAL TRAVERSES FOR THE PHANTOM HOUSE FOR ρ = 63.7 FT

Position	3 ft	5 ft	7 ft	9 ft	11.5 ft	13 ft	15 ft
A	2.30	2.30	2.37	2.30	2.30	2.30	2.23
B	2.67	2.63	2.83	2.67	2.56	2.63	2.50
C	2.37	2.50	2.50		2.76	2.63	2.63
I	2.37	2.56	2.43	2.50	2.37	2.63	2.63

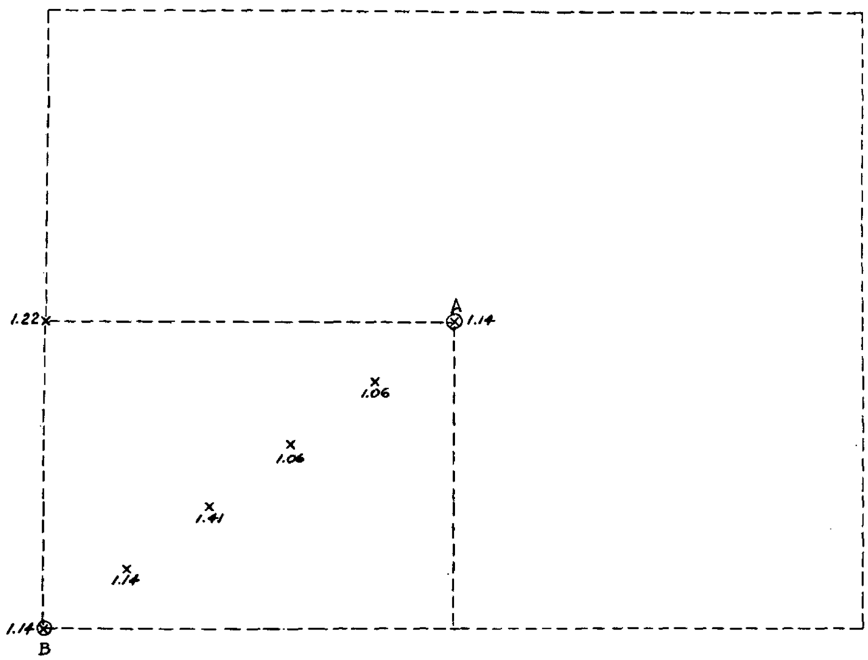

Fig. 3.15—Phantom house, 3-ft level, ρ = 127 ft.

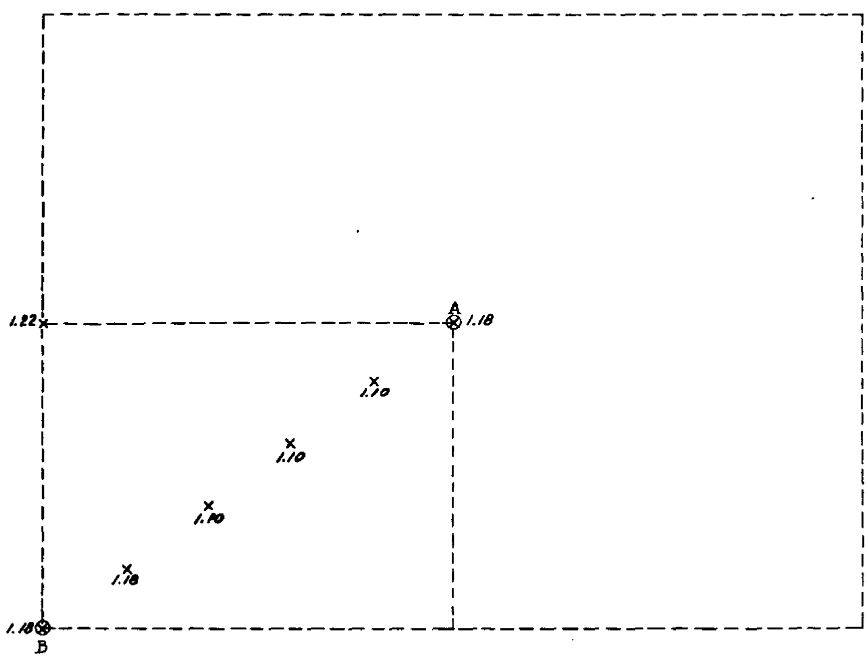

Fig. 3.16—Phantom house, 5-ft level, ρ =127 ft.

TABLE 3.7—VERTICAL TRAVERSES FOR THE PHANTOM HOUSE FOR ρ = 127 FT

Position	1 ft	2 ft	3 ft	4 ft	5 ft	7 ft	9 ft	11.5 ft	13 ft	15 ft
A	1.14	1.14	1.14	1.10	1.18	1.14	1.14	1.18		1.14
B			1.14		1.18	1.18	1.14	1.18	1.30	1.18

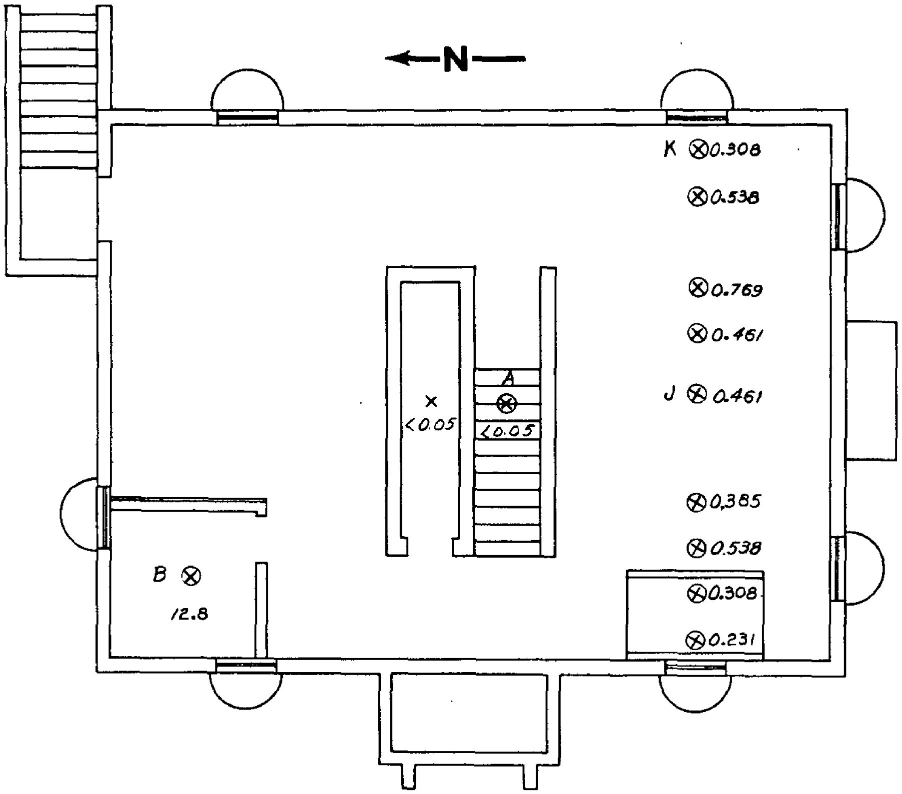

Fig. 3.17—2SWF house, 3-ft level, basement, ρ = 21.2 ft.

TABLE 3.8—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE FOR ρ = 21.2 FT

Position	0.5 ft	1 ft	1.5 ft	2 ft	3 ft	3.5 ft	4.5 ft	5.5 ft	6.5 ft
A	<0.05		<0.05		<0.05	<0.05	<0.4		
B	0.46	0.31	0.31	0.54	12.8			1.08	
K					0.308				6.38
K + 2 ft W					0.538				3.92
K + 6 ft W					0.769				2.61
K + 8 ft W					0.461				2.15
J	0.31	0.31			0.461	0.54	1.08		1.92
J + 4 ft W					0.385				2.00
J + 6 ft W					0.538				2.00
J + 8 ft W					0.308				3.92
J + 10 ft W					0.231				5.84

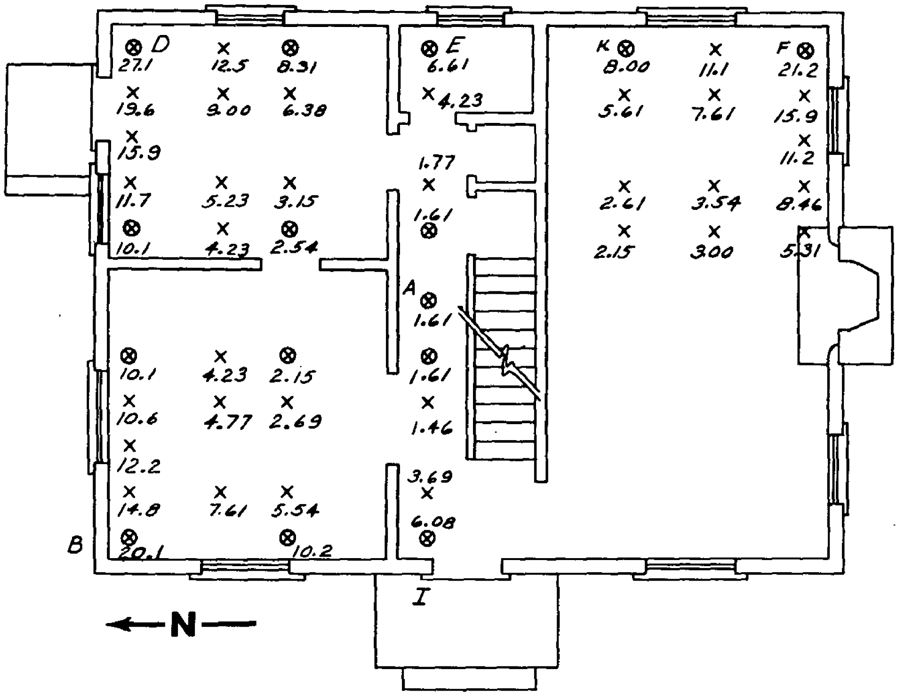

Fig. 3.18—2SWF house, 1-ft level, first floor, ρ = 21.2 ft.

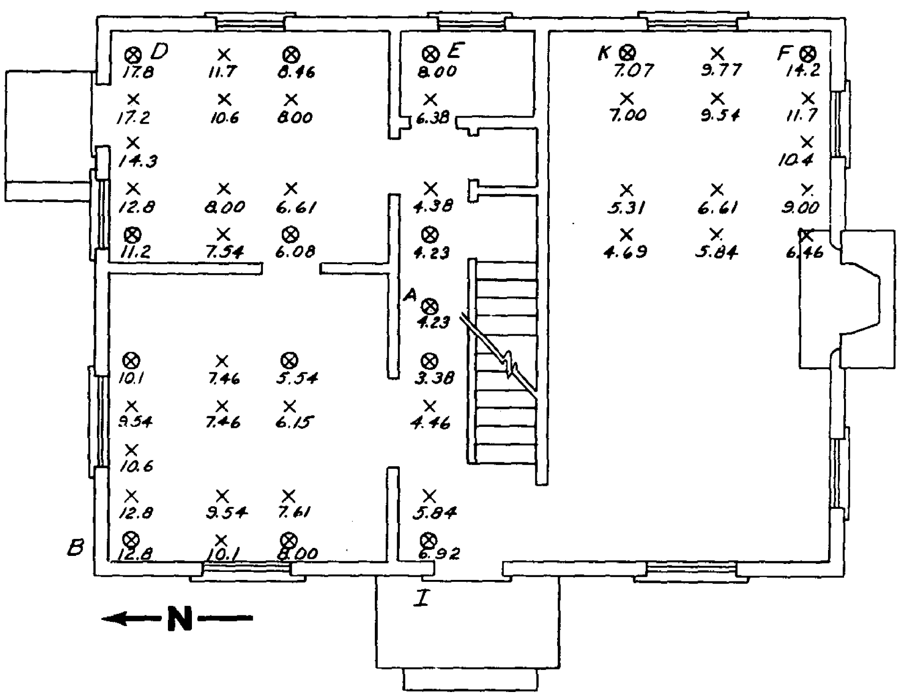

Fig. 3.19—2SWF house, 3-ft level, first floor, ρ = 21.2 ft.

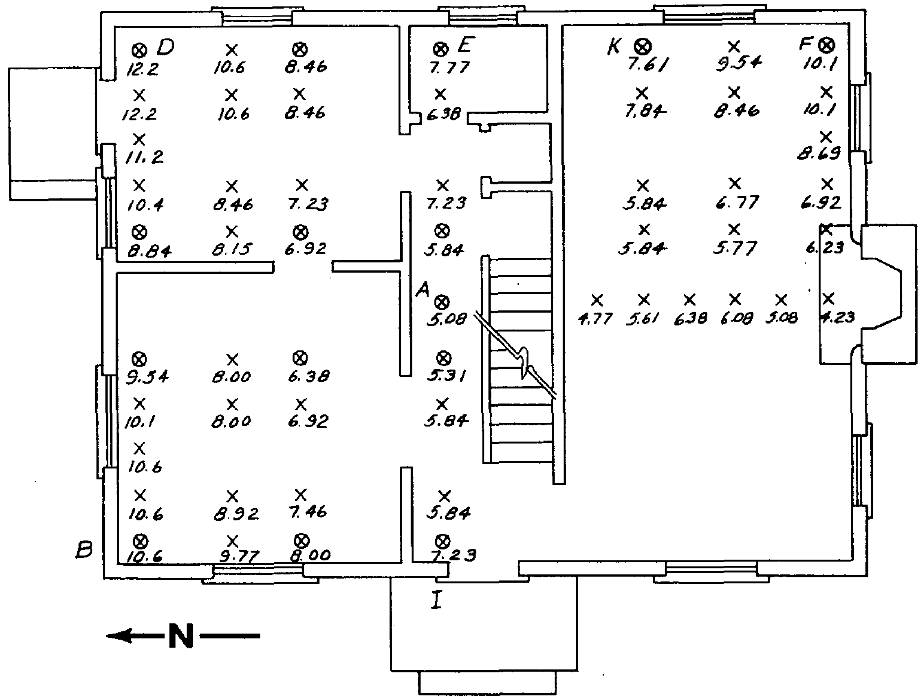

Fig. 3.20—2SWF house, 5-ft level, first floor, ρ = 21.2 ft.

TABLE 3.9—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE FOR ρ = 21.2 FT

Position	1 ft	3 ft	5 ft	7.5 ft
A	1.61	4.23	5.08	
B	20.1	12.8	10.6	7.46
D	27.1	17.8	12.2	9.54
E	6.61	8.00	7.77	6.77
F	21.2	14.2	10.1	
I	6.08	6.92	7.23	6.77
K	8.00	7.07	7.61	
B + 8 ft E	10.1	10.1	9.54	8.00
B + 8 ft S	10.2	8.00	8.00	7.23
B + 8 ft S + 8 ft E	2.15	5.54	6.38	6.08
D + 8 ft W	10.1	11.2	8.84	8.46
D + 8 ft S	8.31	8.46	8.46	7.54
D + 8 ft S + 8 ft W	2.54	6.08	6.92	6.77
E + 8 ft W	1.61	4.23	5.84	
I + 8 ft E	1.61	3.38	5.31	

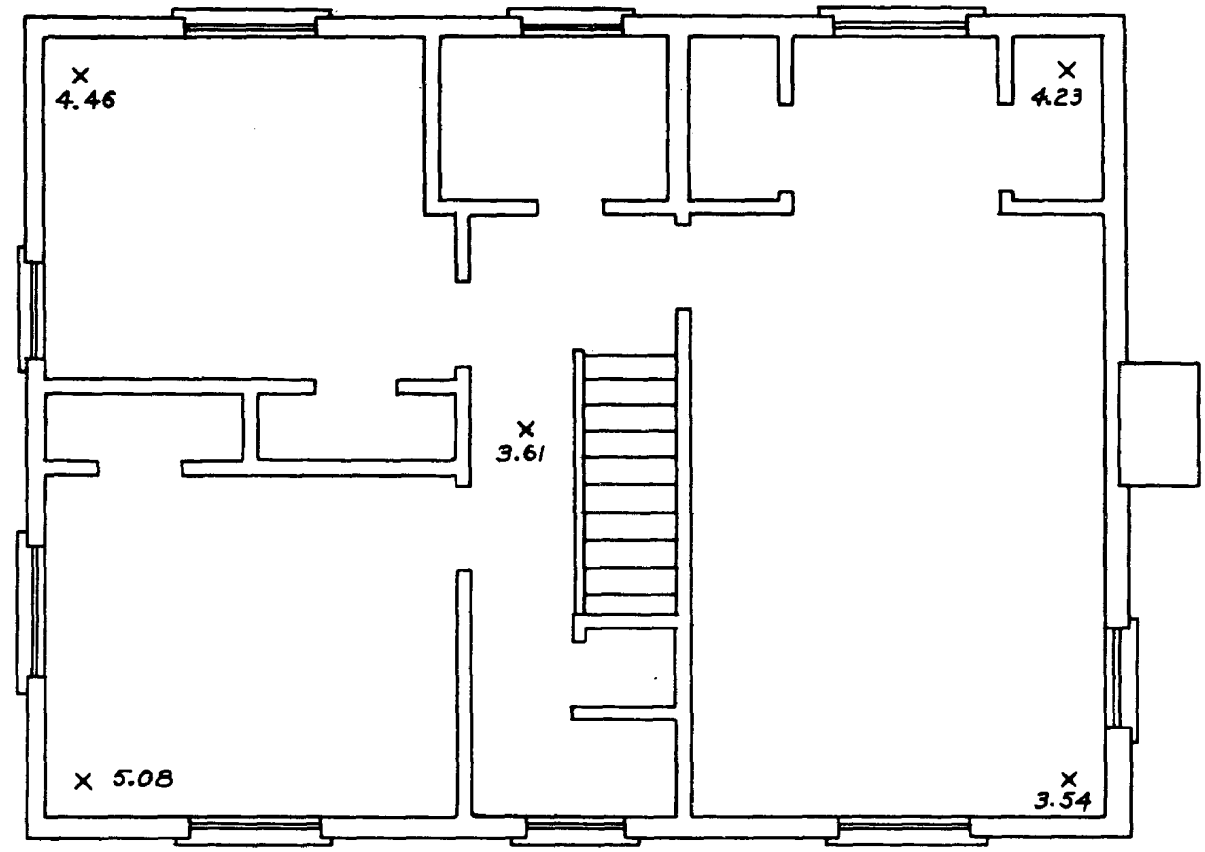

Fig. 3.21—2SWF house, 3-ft level, second floor, ρ = 21.2 ft.

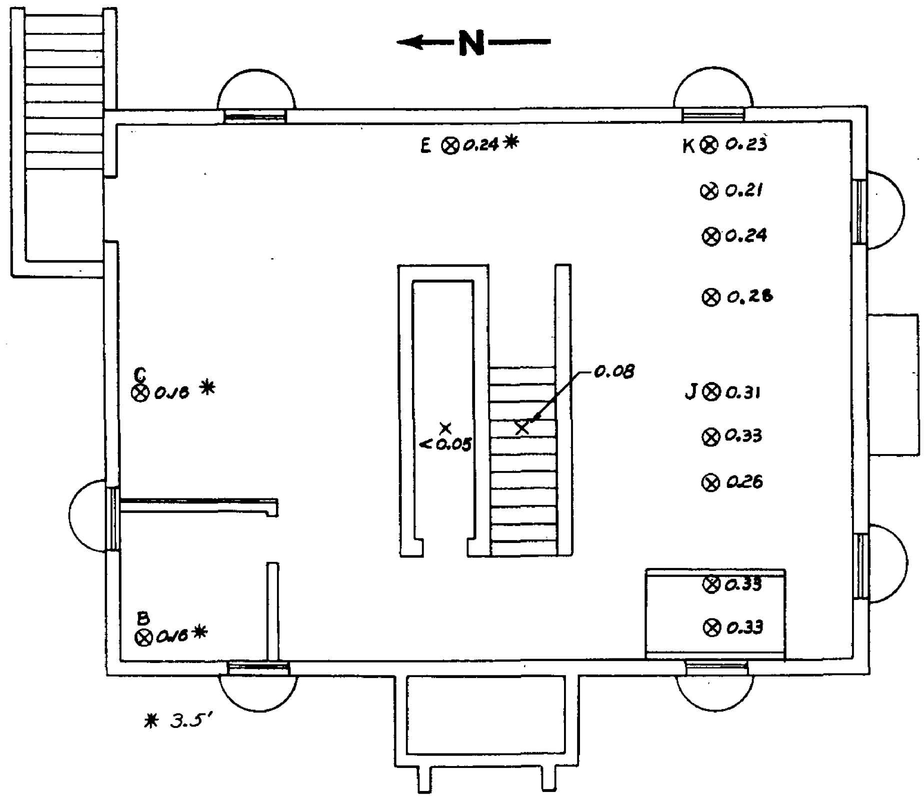

Fig. 3.22—2SWF house, 3-ft level, basement, ρ = 25.5 ft.

TABLE 3.10—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE FOR ρ = 25.5 FT

Position	3 ft	4 ft	5 ft	5.5 ft	6.5 ft
B				0.33	
C					0.73
E					0.49
K	0.23	0.21	0.31		0.98
K + 2 ft W	0.21				0.75
K + 4 ft W	0.24				0.49
K + 6 ft W	0.28				0.54
J	0.31				0.49
J + 2 ft W	0.33				1.10
J + 4 ft W	0.26				1.50
J + 8 ft W	0.33				1.70
J + 10 ft W	0.33				3.40

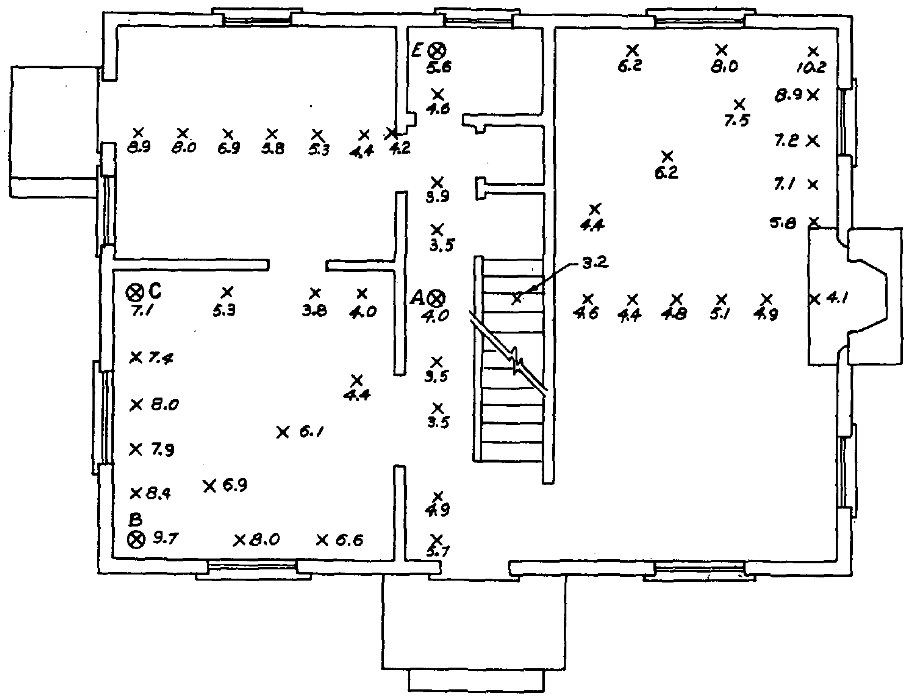

Fig. 3.23—2SWF house, 3-ft level, first floor, ρ = 25.5 ft.

TABLE 3.11—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE FOR ρ = 25.5 FT

Position	1 ft	3 ft	5 ft	7 ft
A	1.3	4.0	4.8	5.2
B	10.6	9.7	9.3	7.4
C	5.4	7.1	7.1	6.6
E	4.4	5.6	6.2	6.2

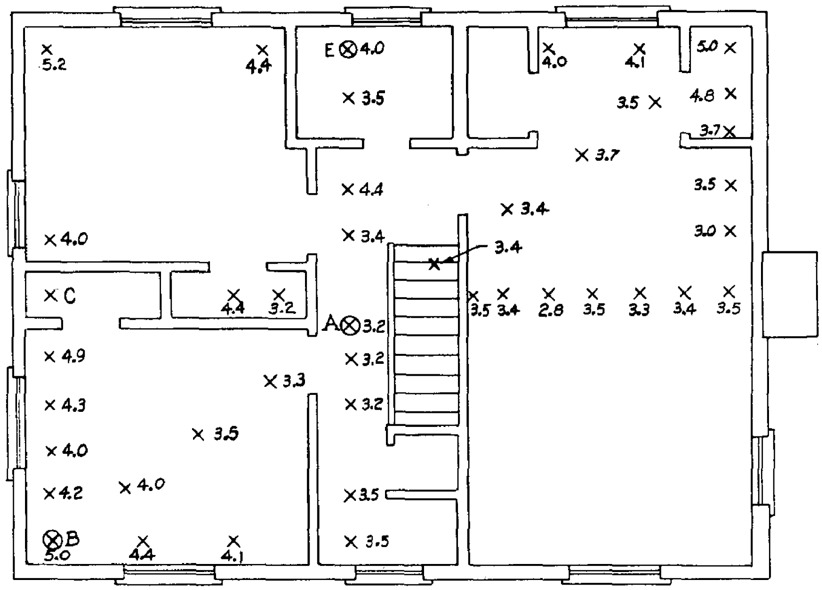

Fig. 3.24—2SWF house, 3-ft level, second floor, ρ = 25.5 ft.

TABLE 3.12—VERTICAL TRAVERSES FOR THE SECOND FLOOR OF THE 2SWF HOUSE FOR ρ = 25.5 FT

Position	1 ft	3 ft	5 ft	7 ft
A	3.1	3.2	2.7	2.7
B	5.3	5.0	4.3	3.5
C	4.0		3.5	3.1
E	3.8	4.0	3.5	3.4

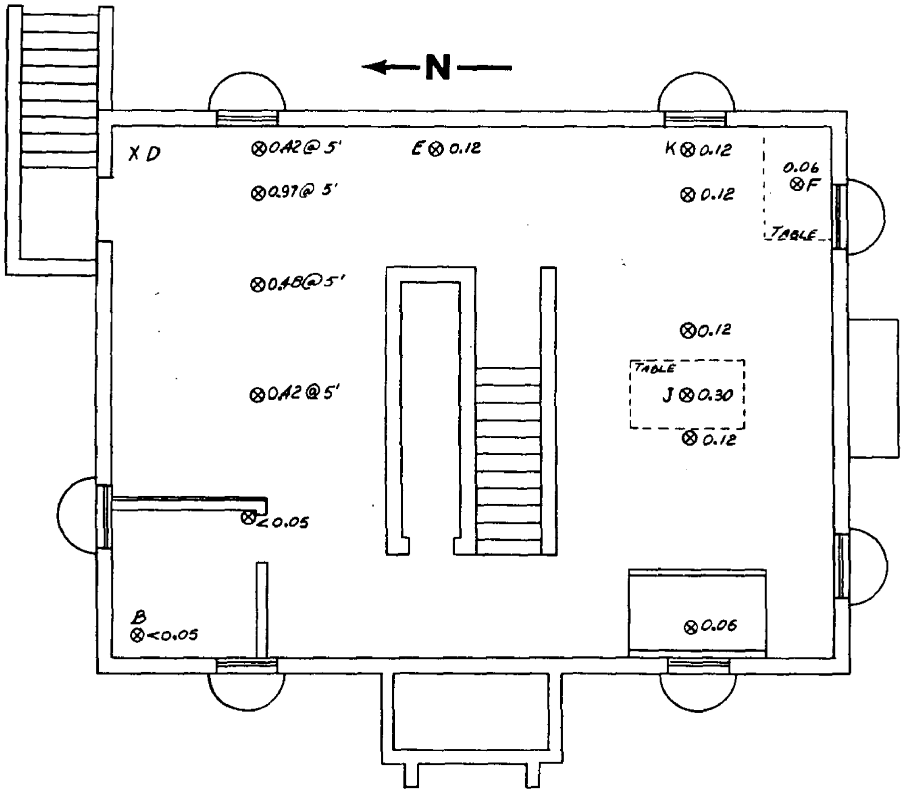

Fig. 3.25—2SWF house, 3-ft level, basement, ρ = 31.8 ft.

TABLE 3.13—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE FOR ρ = 31.8 FT

Position	1 ft	2 ft	3 ft	5 ft	6.5 ft
B	<0.05		<0.05	<0.05	
C	0.06				0.18
E	<0.05		0.12		0.30
F	<0.05	<0.05	0.06*	0.18	0.60
K			0.12		0.42
K + 2 ft W			0.12		0.48
K + 8 ft W			0.12		0.30
J	0.06	<0.05	0.30*	0.30	0.30
J + 2 ft W			0.12		0.30
J + 10 ft W			0.06		0.36
D + 6 ft S	0.06			0.42	
D + 6 ft S + 2 ft W	0.12			0.97	
D + 6 ft S + 6 ft W	0.18			0.48	
D + 6 ft S + 11 ft W	0.18			0.42	
D + 6 ft S + 15½ ft W	<0.05		<0.05	0.18	

*One in. above blocks that were on the table top.

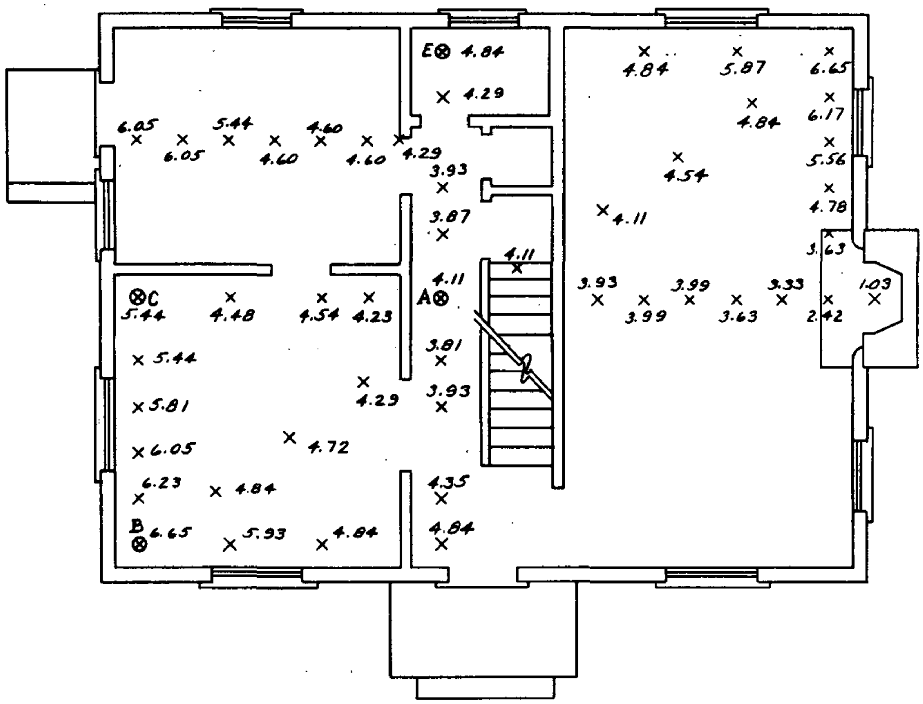

Fig. 3.26—2SWF house, 3-ft level, first floor, ρ = 31.8 ft.

TABLE 3.14—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE FOR ρ = 31.8 FT

Position	1 ft	3 ft	5 ft	7 ft
A	1.03	4.11	3.75	3.93
B	6.65	6.65	6.65	5.87
C	4.78	5.44	6.05	5.44
E	3.21	4.84	4.84	4.35

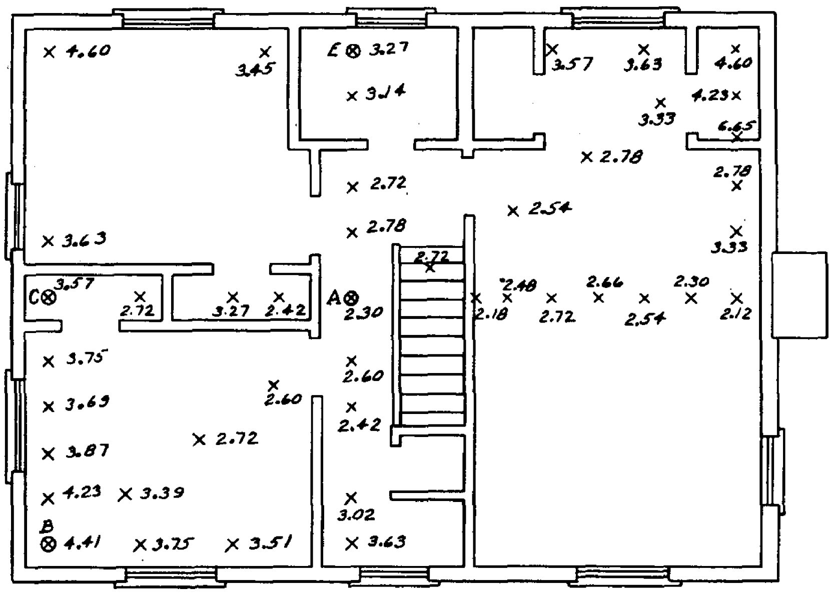

Fig. 3.27—2SWF house, 3-ft level, second floor, ρ = 31.8 ft.

TABLE 3.15—VERTICAL TRAVERSES FOR THE SECOND FLOOR OF THE 2SWF HOUSE FOR ρ = 31.8 FT

Position	1 ft	3 ft	5 ft	7 ft
A	2.42	2.30	2.42	2.42
B	4.41	4.41	4.05	3.75
C	3.02	3.57	3.33	3.27
E	3.14	3.27	2.96	3.02

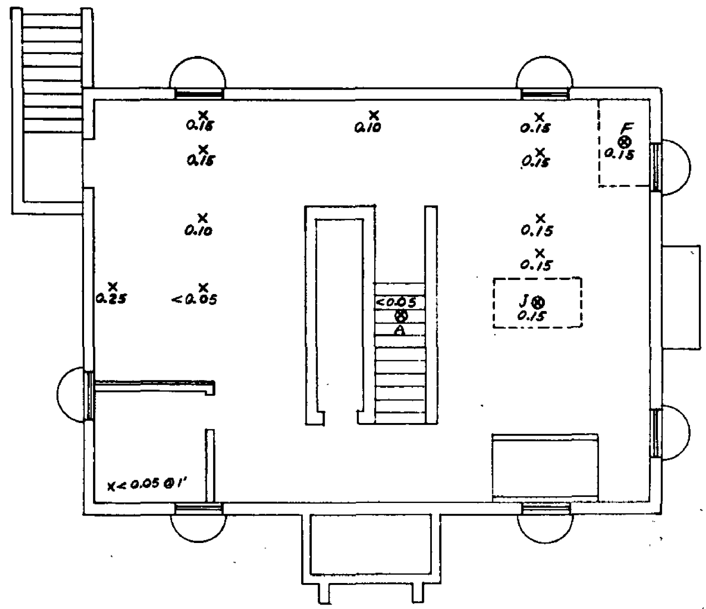

Fig. 3.28—2SWF house, 3-ft level, basement, furniture in house, ρ = 31.8 ft.

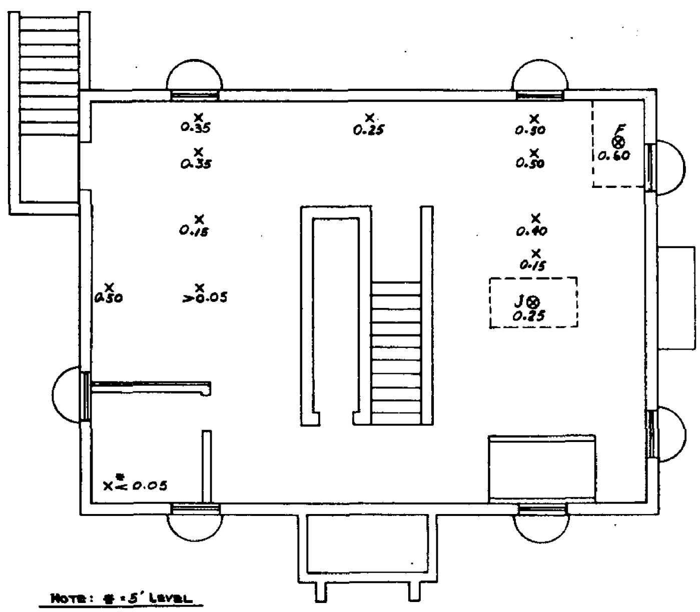

Fig. 3.29—2SWF house, 6.5-ft level, basement, furniture in house, ρ = 31.8 ft.

TABLE 3.16—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE (CONTAINING FURNITURE) FOR ρ = 31.8 FT

Position	1 ft	2 ft	3 ft	4.5 ft	5 ft	6.5 ft
A	<0.05		<0.05	<0.05		
F	<0.05	<0.05	0.15*		0.20	0.60
J	<0.05		0.15*		0.25	0.25

*One in. above concrete blocks on table top.

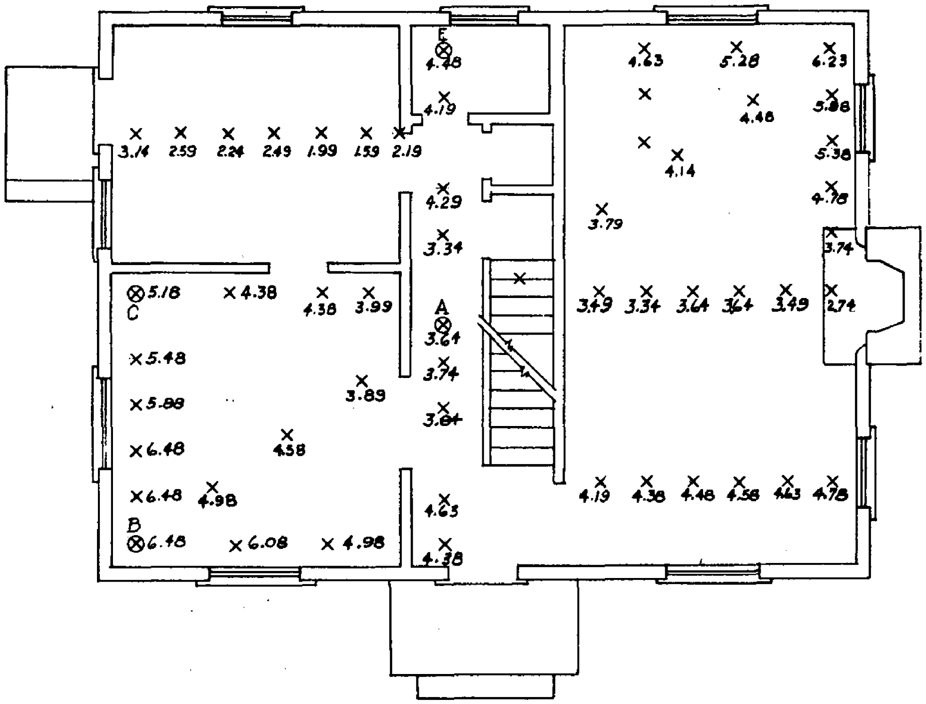

Fig. 3.30—2SWF house, 3-ft level, first floor, furniture in house, ρ = 31.8 ft.

TABLE 3.17—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE (CONTAINING FURNITURE) FOR ρ = 31.8 FT

Position	1 ft	3 ft	5 ft	7 ft
A	0.90	3.64	3.99	
B	6.38	6.48	6.38	5.98
C	4.38	5.18	5.18	5.38
E	3.24	4.48	4.38	4.48

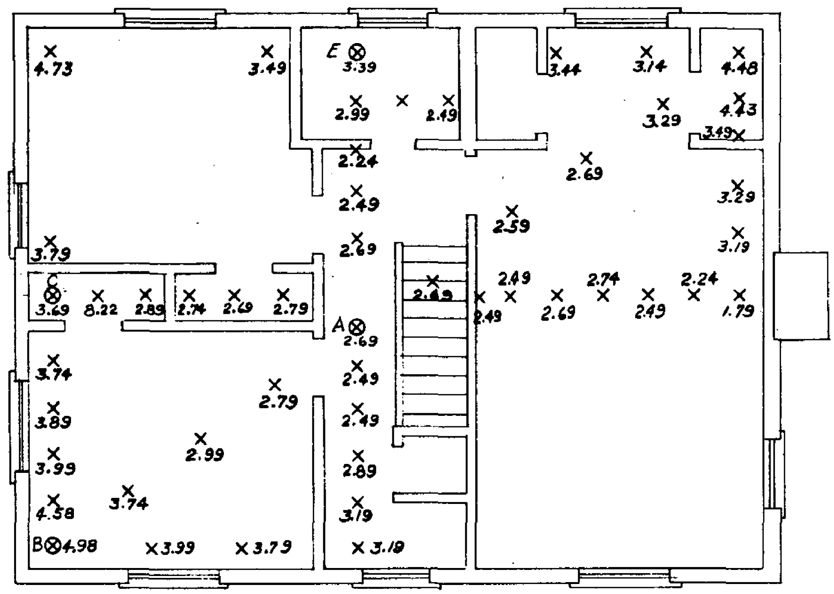

Fig. 3.31—2SWF house, 3-ft level, second floor, furniture in house, ρ = 31.8 ft.

TABLE 3.18—VERTICAL TRAVERSES FOR THE SECOND FLOOR OF THE 2SWF HOUSE (CONTAINING FURNITURE) FOR ρ = 31.8 FT

Position	1 ft	3 ft	5 ft	7 ft
A	2.69	2.69		
B	4.38	4.98	3.99	3.99
C	3.49	3.69	3.39	
E	2.19	3.39	3.39	3.19

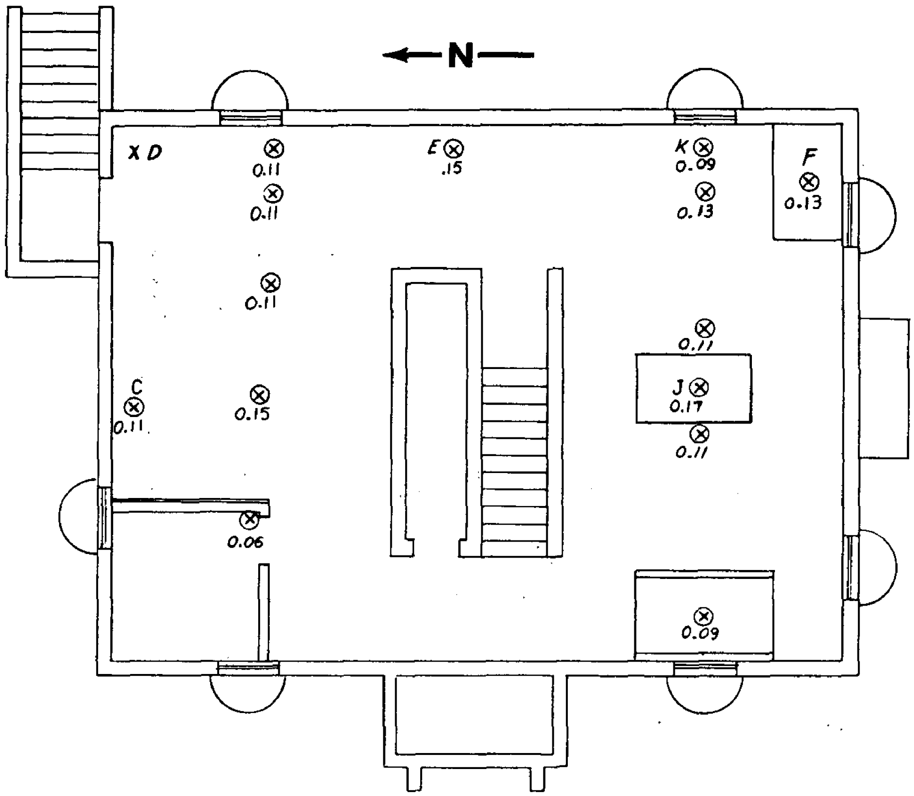

Fig. 3.32—2SWF house, 3-ft level, basement, $\rho = 42.5$ ft.

TABLE 3.19—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE FOR $\rho = 42.5$ FT

Position	1 ft	2 ft	3 ft	5 ft	6.5 ft
C			0.11		0.37
E			0.15		0.26
K			0.09		0.32
K + 2 ft W			0.13		0.43
K + 8 ft W			0.11		0.26
J	<0.05	0.06	0.17*	0.22	0.22
J + 2 ft W	<0.05		0.11		0.32
J + 10 ft W			0.09		0.37
F	0.09	<0.05	0.13*	0.17	0.32
D + 5 ft S			0.11		0.32
D + 5 ft S + 2 ft W			0.11		0.30
D + 5 ft S + 6 ft W			0.11		0.39
D + 5 ft S + 10 ft W			0.15		0.30
D + 5 ft S + 14.5 ft W			0.06	0.11	

*One in. above concrete blocks on table top.

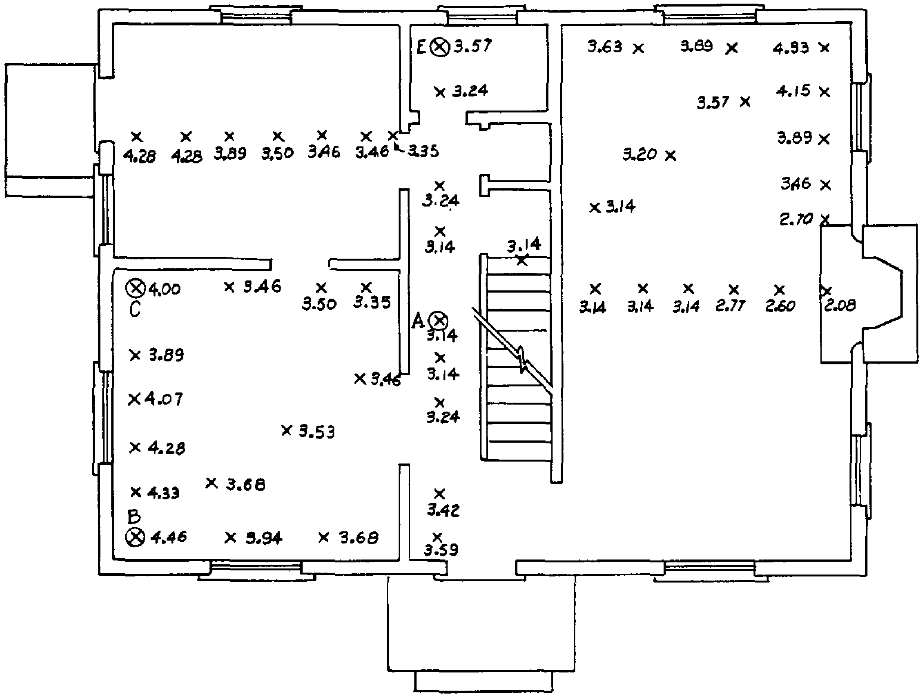

Fig. 3.33—2SWF house, 3-ft level, first floor, ρ = 42.5 ft.

TABLE 3.20—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE FOR ρ = 42.5 FT

Position	1 ft	3 ft	5 ft	7 ft
A	1.47	3.14	3.03	3.24
B	4.20	4.46	>4.54	4.43
C	3.59	4.00	4.33	4.11
E	2.27	3.57	3.63	3.24

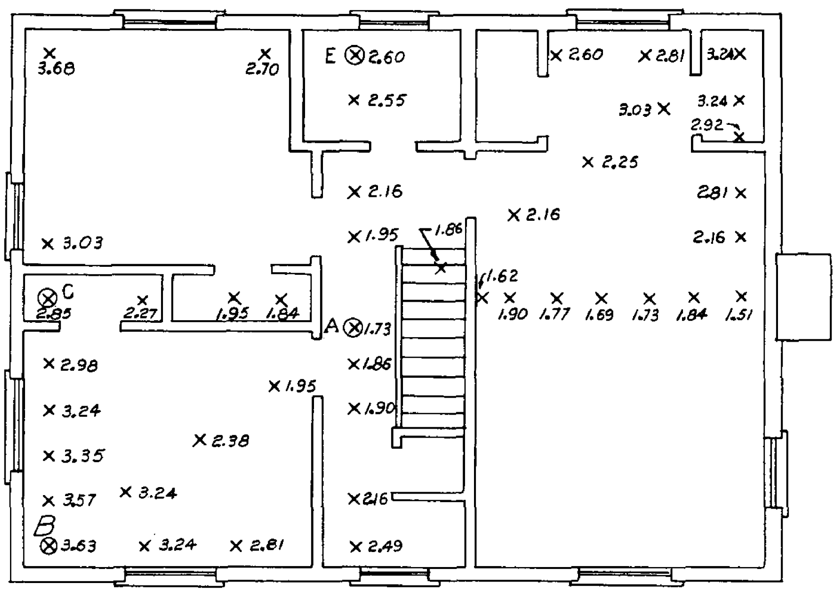

Fig. 3.34—2SWF house, 3-ft level, second floor, ρ = 42.5 ft.

Table 3.21—VERTICAL TRAVERSES FOR THE SECOND FLOOR OF THE 2SWF HOUSE FOR ρ = 42.5 FT

Position	1 ft	3 ft	5 ft	7 ft
A	1.77	1.73	1.99	2.51
B	3.50	3.63	3.55	3.35
C	2.70	2.85	3.03	3.24
E	2.47	2.60	2.38	2.60

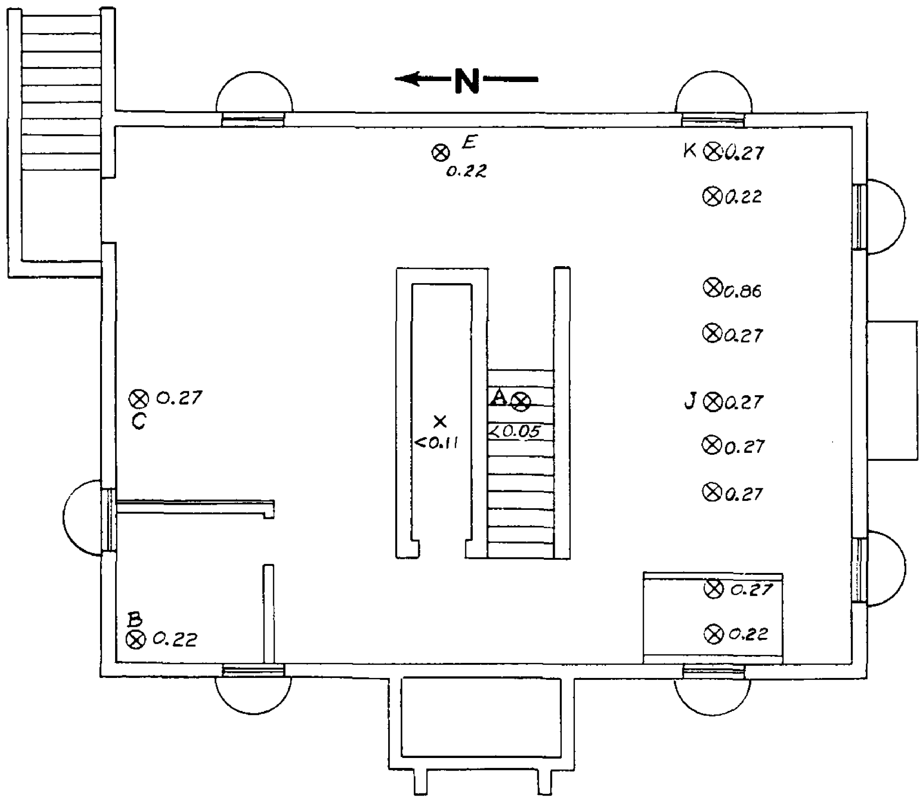

Fig. 3.35—2SWF house, 3-ft level, basement, ρ = 63.7 ft. (All values should be multiplied by 0.337.)

TABLE 3.22—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE FOR ρ = 63.7 FT*

Position	0.5 ft	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	6.5 ft	7 ft
A		<0.05	0.16	<0.05	0.16	0.16			
B	<0.05		0.05	0.22	0.22	0.22			
C		0.16		0.27	0.27	0.38	0.48		0.86
E		0.16	0.16	0.22	0.27	0.27	0.38		0.65
K				0.27				1.60	
K + 2 ft W				0.22				1.9	
K + 6 ft W				0.86				1.3	
K + 8 ft W				0.27				1.9	
J	0.16	0.27	0.27	0.27	0.32	0.59		1.0	
J + 2 ft W				0.27				1.1	
J + 4 ft W				0.27				1.1	
J + 8 ft W				0.27				1.6	
J + 10 ft W				0.22				1.5	

*All values should be multiplied by 0.337.

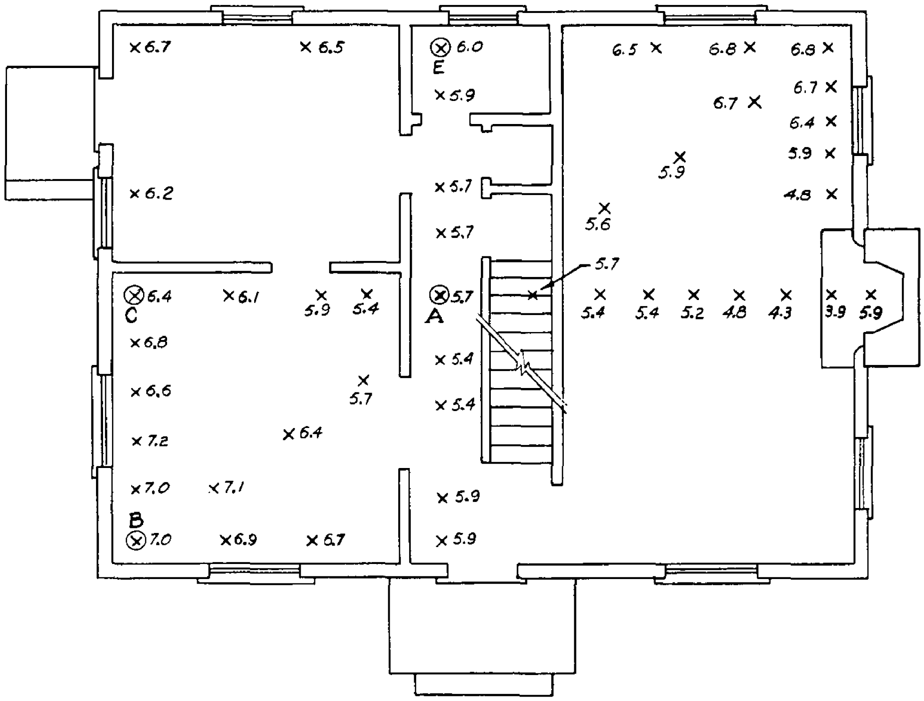

Fig. 3.36—2SWF house, 3-ft level, first floor, ρ = 63.7 ft. (All values should be multiplied by 0.337.)

TABLE 3.23—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE FOR ρ = 63.7 FT*

Position	1 ft	3 ft	5 ft	7 ft
A	4.8	5.7	5.9	5.9
B	6.9	7.0	7.7	7.5
C	5.7	6.4	6.8	6.7
E	5.4	6.0	6.3	5.8

*All values should be multiplied by 0.337.

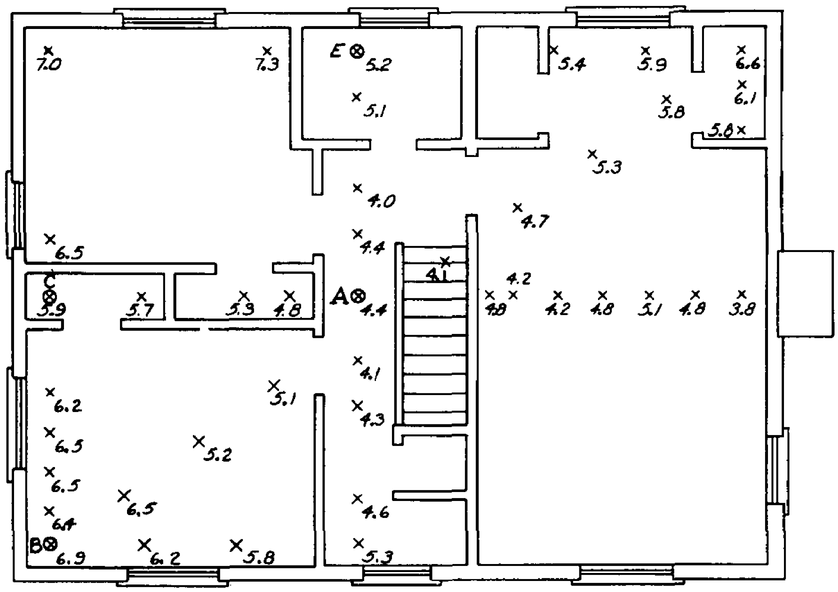

Fig. 3.37—2SWF house, 3-ft level, second floor, ρ = 63.7 ft. (All values should be multiplied by 0.337.)

TABLE 3.24—VERTICAL TRAVERSES FOR THE SECOND FLOOR OF THE 2SWF HOUSE FOR ρ = 63.7 FT*

Position	1 ft	3 ft	5 ft	7 ft
A	2.9	4.4	6.1	5.9
B	6.5	6.9	7.4	7.3
C	4.8	5.9	6.5	6.9
E	4.5	5.2	5.9	6.5

*All values should be multiplied by 0.337.

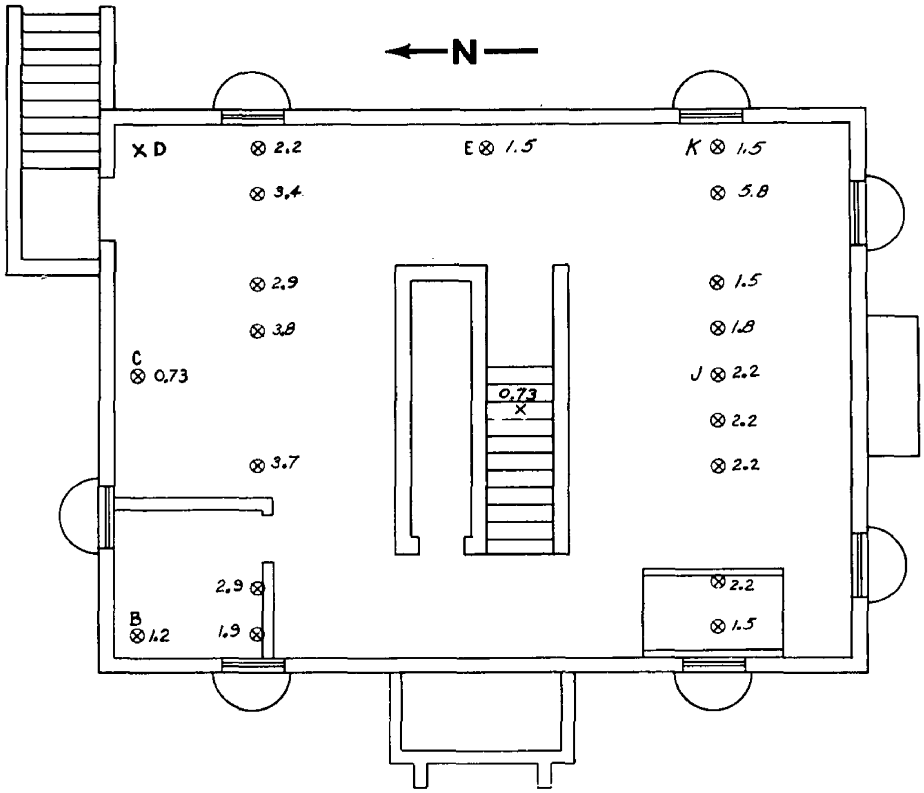

Fig. 3.38—2SWF house, 3-ft level, basement, fill-in sources.

TABLE 3.25—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE FOR FILL-IN SOURCES

Position	3 ft	5 ft	6.5 ft
B	1.2	2.9	
C	0.73		12.3
E	1.5		7.9
K	1.5		10.8
K + 2 ft W	5.8		11.0
K + 6 ft W	1.5		2.9
K + 8 ft W	1.8		3.4
J	2.2		2.9
J + 2 ft W	2.2		3.2
J + 4 ft W	2.2		5.1
J + 8 ft W	2.2		5.4
J + 10 ft W	1.5		10.5
D + 5 ft S	2.2		33
D + 5 ft S + 2 ft W	3.4		16.1
D + 5 ft S + 6 ft W	2.9		8.8
D + 5 ft S + 8 ft W	3.8		
D + 5 ft S + 10 ft W			7.3
D + 5 ft S + 14 ft W	3.7		7.3
B + 5 ft S	1.9		37*
B + 5 ft S + 2 ft E	2.9		11.7*

*Top of shelter.

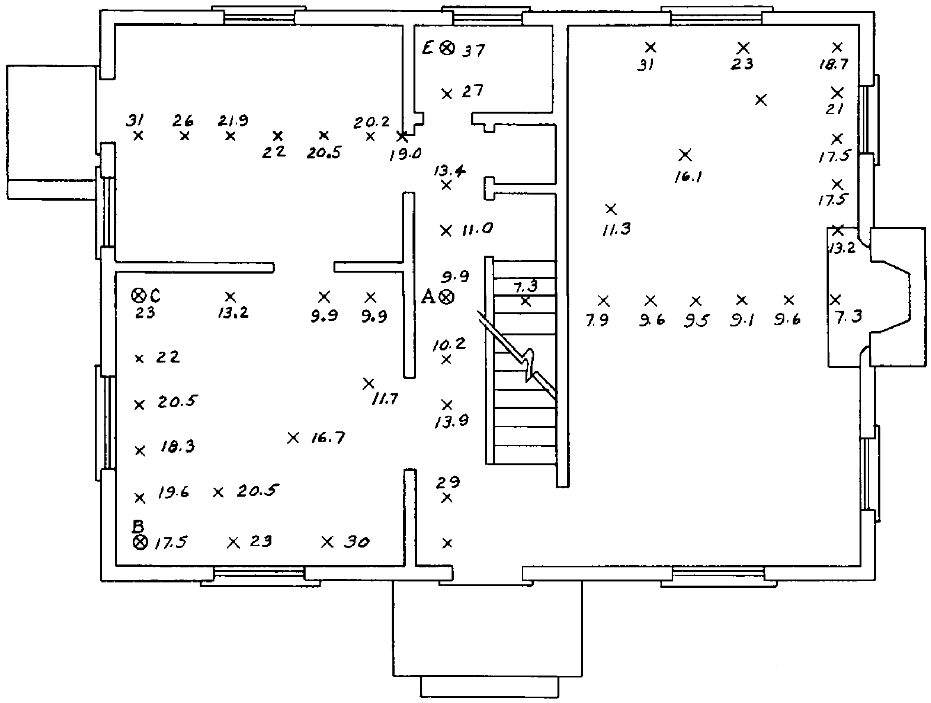

Fig. 3.39—2SWF house, 3-ft level, first floor, fill-in sources.

TABLE 3.26—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE FOR FILL-IN SOURCES

Position	1 ft	3 ft	5 ft	7 ft
A	5.1	9.9	13.2	14.9
B	19.0	17.5	15.5	12.4
C	27	23	17.5	14.3
E		37	26.0	21.2

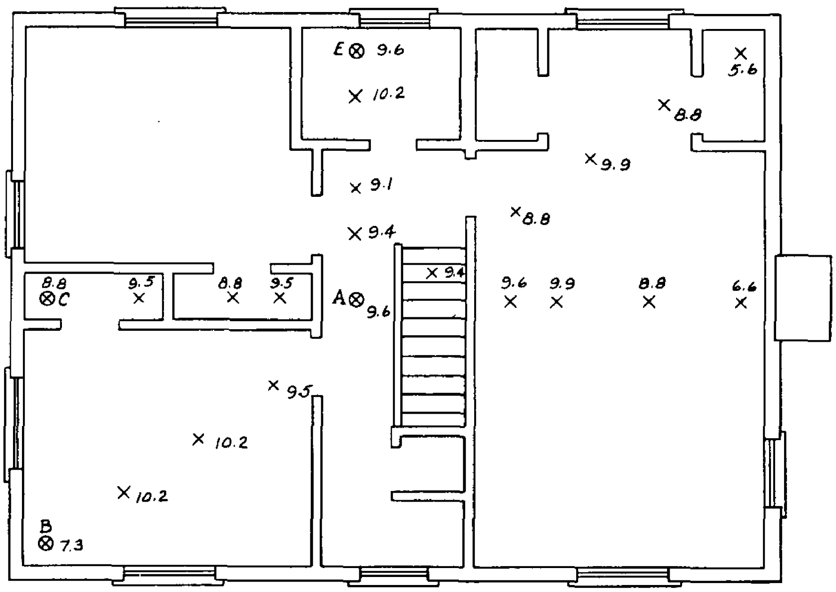

Fig. 3.40—2SWF house, 3-ft level, second floor, fill-in sources.

TABLE 3.27—VERTICAL TRAVERSES FOR THE SECOND FLOOR OF THE 2SWF HOUSE FOR FILL-IN SOURCES

Position	1 ft	3 ft	5 ft	7 ft
A	10.2	9.6	9.4	8.0
B	8.0	7.3	5.6	5.0
C	8.8	8.8	7.3	6.1
E	12.4	9.6	8.8	7.3

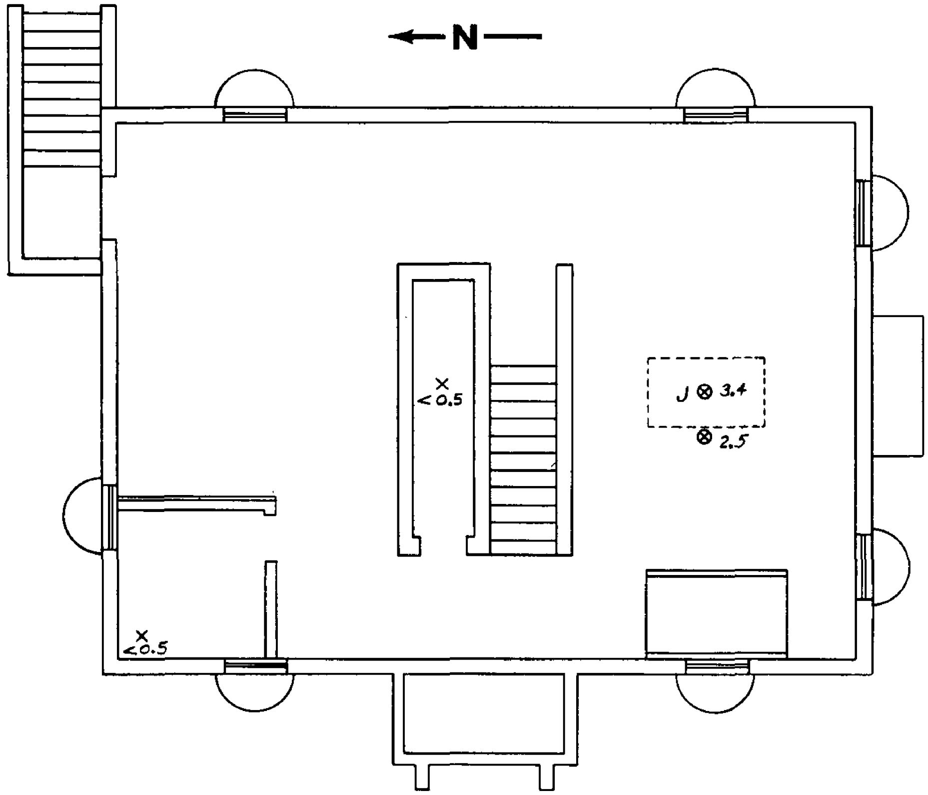

Fig. 3.41—2SWF house, 3-ft level, basement, sources on west half of roof.

TABLE 3.28—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE FOR SOURCES ON WEST HALF OF ROOF

Position	1 ft	2 ft	3 ft	5 ft	6.5 ft
J	<0.05	<0.05	3.4*	3.4	4.2
J + 2 ft W	2.5	2.5	2.5	4.2	

*One in. above top of concrete blocks on table top.

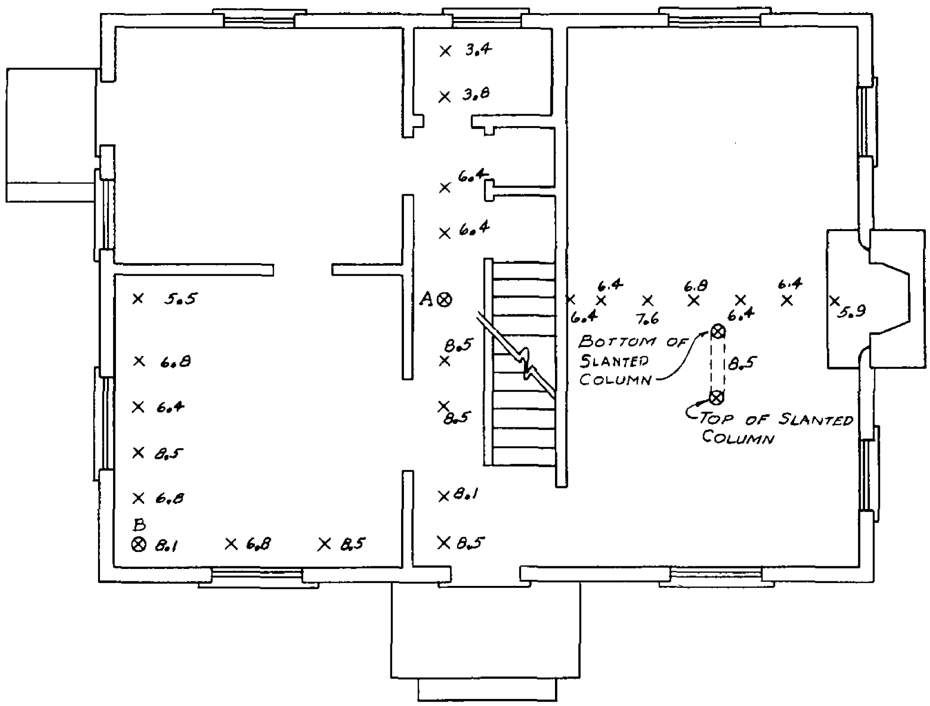

Fig. 3.42—2SWF house, 3-ft level, first floor, sources on west half of roof.

TABLE 3.29—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE FOR SOURCES ON WEST HALF OF ROOF

Position	Floor	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	Ceiling
A		6.4				8.5		21.2	
B		6.4		8.1		7.6		8.5	
Slanted column*	5.5	6.4	7.6	8.5	8.9	8.5	10.2	10.6	10.6

*Measured along slant.

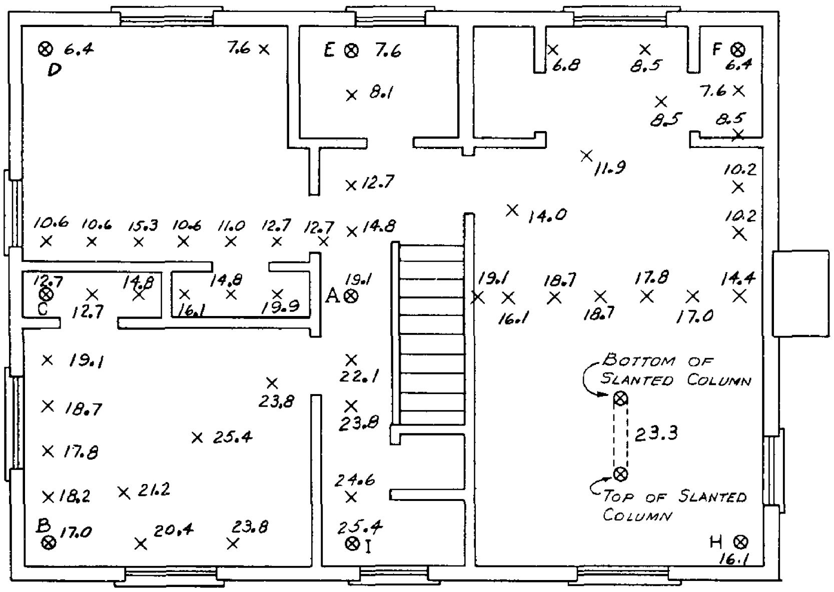

Fig. 3.43—2SWF house, 3-ft level, second floor, sources on west half of roof.

TABLE 3.30—VERTICAL TRAVERSES FOR THE SECOND FLOOR OF THE 2SWF HOUSE FOR SOURCES ON WEST HALF OF ROOF

Position	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	Ceiling
A	15.3		19.1		23.3		27.6		
B	14.4		17.0		21.2		27.6		
C	11.9		12.7		14.4		21.2		
D	5.1		6.4		7.6		5.1		
E	6.8		7.6		7.6		8.5		
F	5.1		6.4		8.5		5.1		
H	12.7		16.1		17.0		16.1		
I	20.4		25.4		32.2		48.4		
Slanted column*	19.1	18.2	23.3	25.4	31.4	33.9	40.3	46.7	59.4

*Measured along slant.

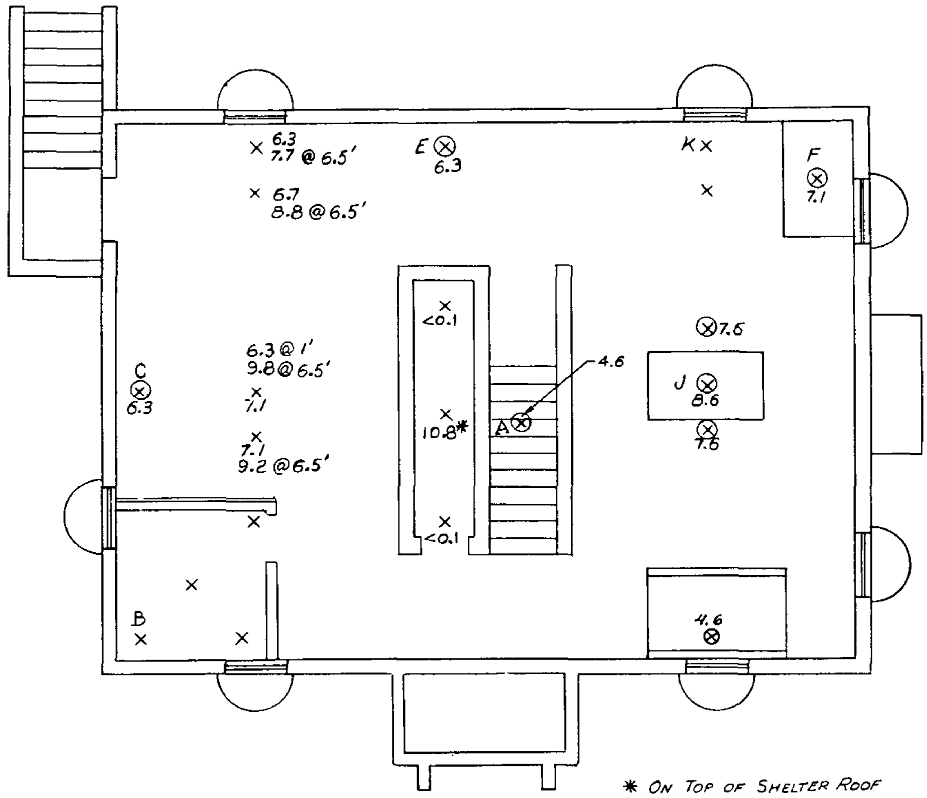

Fig. 3.44—2SWF house, 3-ft level, basement, sources on entire roof area.

TABLE 3.31—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE FOR SOURCES ON ENTIRE ROOF AREA

Position	1 ft	2 ft	3 ft	4 ft	5 ft	6.5 ft
A	2.9		4.6	6.9		
B	1.1				0.8	
C	5.9		6.3			7.1
E			6.3			7.5
K	6.2					7.6
F	1.8	0.8	7.1*		7.8	
B + 3 ft SE	2.5				1.0	
B + 6 ft S	2.8				2.9	8.6†
B + 7 ft SE	4.2				4.6	10.8†
K + 2 ft W	7.1					8.0
K + 8 ft W	5.7		7.6			8.5
J	1.1	1.1	8.6*		9.4	10.8
J + 2 ft W	5.7		7.6			9.6
J + 10 ft W			4.6			6.9

*One in. above concrete blocks on table top.
†On top of blocks atop shelter.

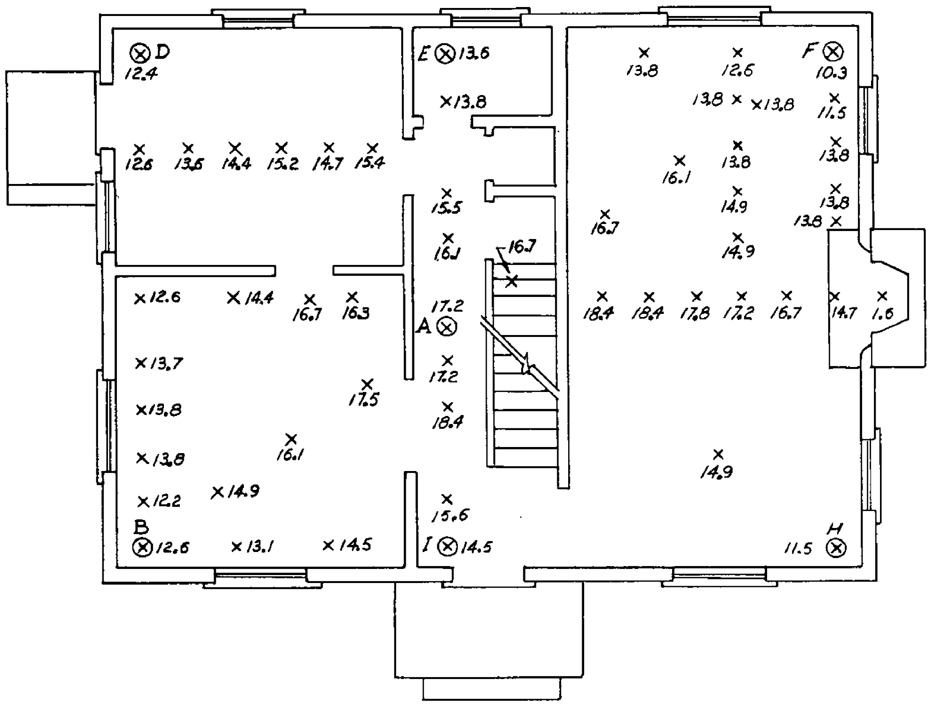

Fig. 3.45—2SWF house, 3-ft level, first floor, sources on entire roof area.

TABLE 3.32—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE FOR SOURCES ON ENTIRE ROOF AREA

Position	1 ft	3 ft	5 ft	7 ft
A	14.4	17.2	20.7	25.3
B	10.9	12.6	12.6	15.8
D	10.3	12.4	12.6	15.4
E	11.5	13.6	16.7	18.9
F	9.8	10.3	11.5	12.1
H	10.9	11.5	13.6	15.5
I	13.0	14.5	17.2	17.9

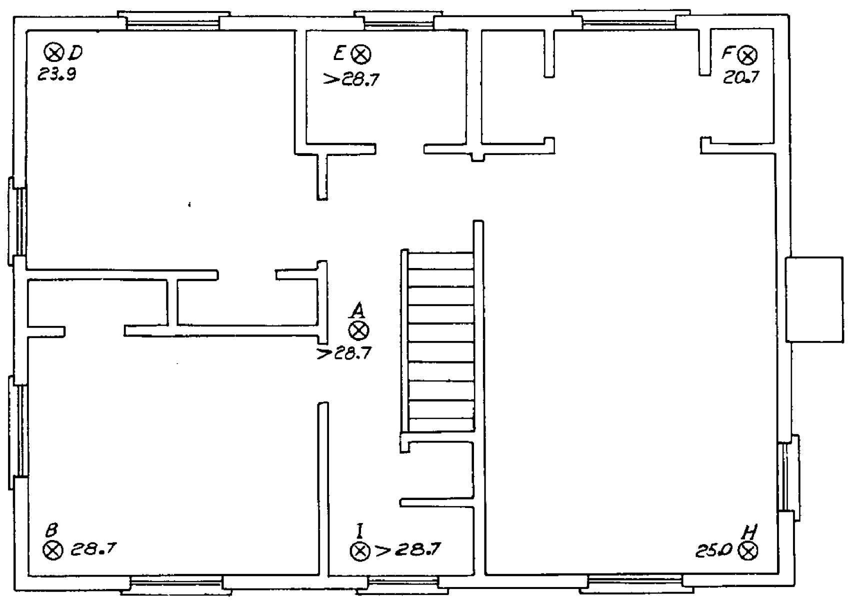

Fig. 3.46—2SWF house, 3-ft level, second floor, sources on entire roof area.

TABLE 3.33—VERTICAL TRAVERSES FOR THE SECOND FLOOR OF THE 2SWF HOUSE FOR SOURCES ON ENTIRE ROOF AREA

Position	1 ft	3 ft	5 ft	7 ft
A	>28.7	>28.7	>28.7	>28.7
B	20.9	28.7	28.7	
D	20.7	23.9	27.6	>28.7
E	26.4	>28.7	>28.7	
F	17.8	20.7	24.1	>28.7
H	20.9	25.0	28.7	>28.7
I	27.6	>28.7	>28.7	

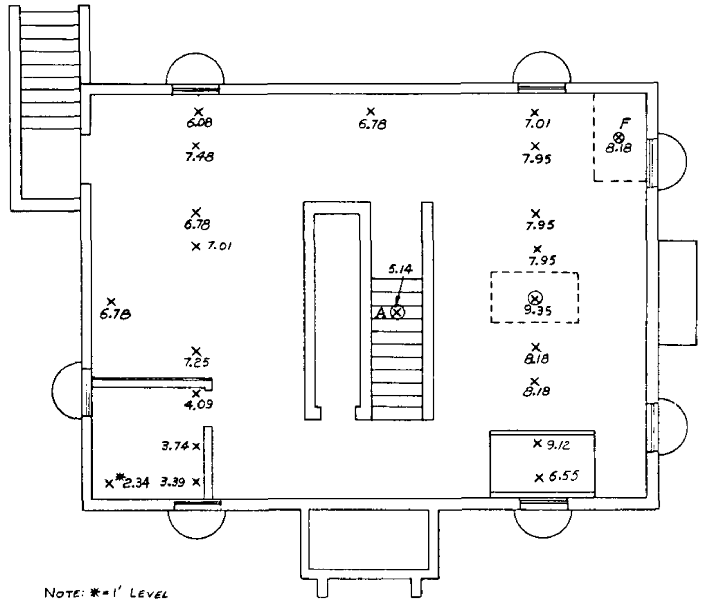

Fig. 3.47—2SWF house, 3-ft level, basement, sources on entire roof area, furniture in house. (Value for point A is for the 3.5-ft level.)

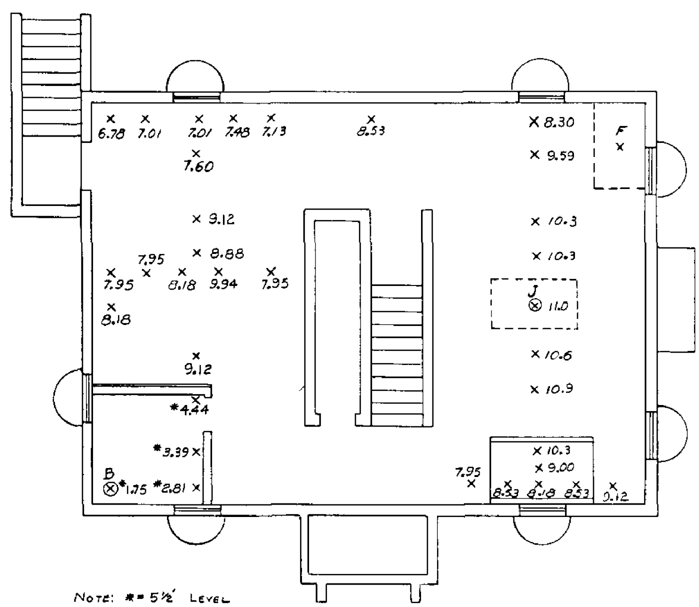

Fig. 3.48—2SWF house, 6.5-ft level, basement, sources on entire roof area, furniture in house.

TABLE 3.34—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SWF HOUSE (CONTAINING FURNITURE) FOR SOURCES ON ENTIRE ROOF AREA

Position	1 ft	1.5 ft	2 ft	3 ft	3.5 ft	4.5 ft	5 ft	6.5 ft
A		3.16			5.14	6.43		
F	7.95		8.53	8.18*			8.53	
J	1.75		2.10	9.35*			10.1	11.0

*One in. above top of concrete blocks on table top.

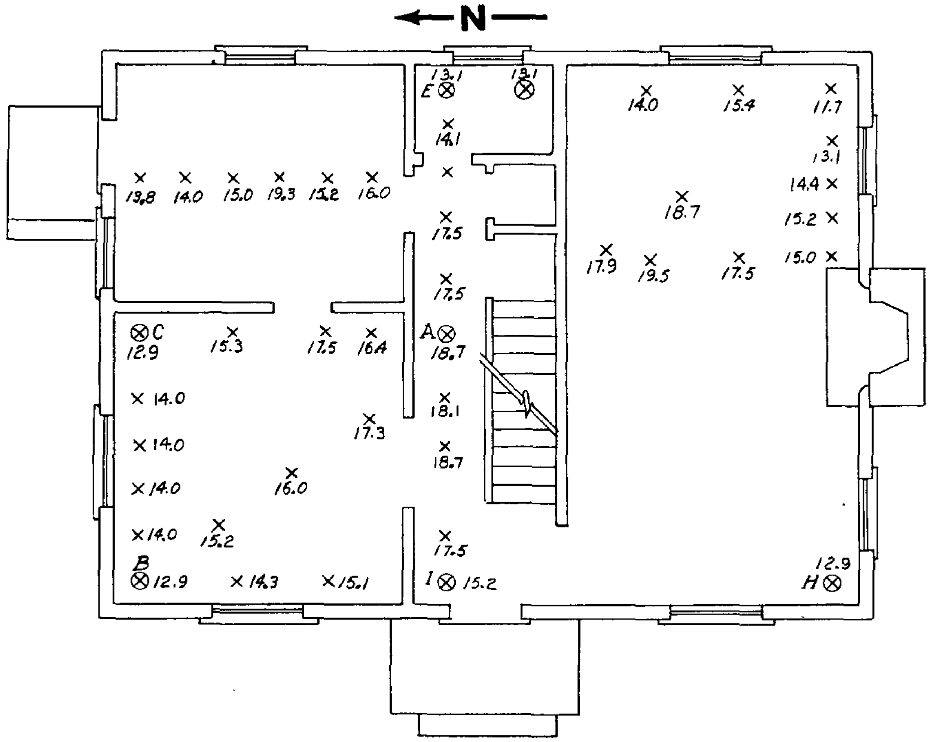

Fig. 3.49—2SWF house, 3-ft level, first floor, sources on entire roof area, furniture in house.

TABLE 3.35—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SWF HOUSE (CONTAINING FURNITURE) FOR SOURCES ON ENTIRE ROOF AREA

Position	1 ft	3 ft	5 ft	7 ft
A	16.0	18.7	24.0	
B	14.1	12.9	17.5	17.5
C	10.8	12.9	15.4	18.1
E	11.3	13.1	14.8	16.1
E + 3 ft S	10.9	13.1	14.6	15.8
H	11.6	12.9	12.9	17.2
I	13.4	15.2	17.5	20.2

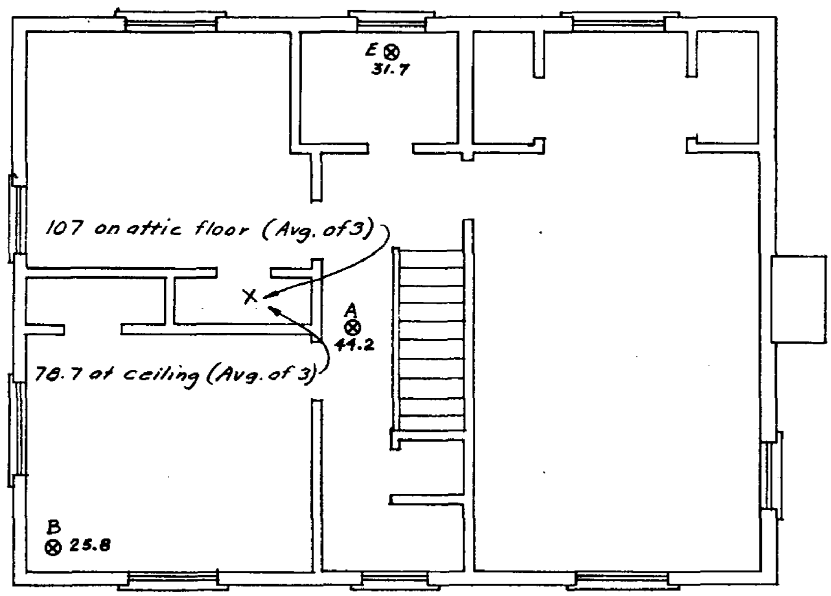

Fig. 3.50—2SWF house, 3-ft level, second floor, sources on entire roof area, furniture in house.

TABLE 3.36—VERTICAL TRAVERSES FOR THE SECOND FLOOR OF THE 2SWF HOUSE (CONTAINING FURNITURE) FOR SOURCES ON ENTIRE ROOF AREA

Position	1 ft	3 ft	5 ft	7 ft
A	36.9	44.2	59.0	73.7
B	22.1	25.8	36.9	29.5
E	28.0	31.7	42.8	51.6

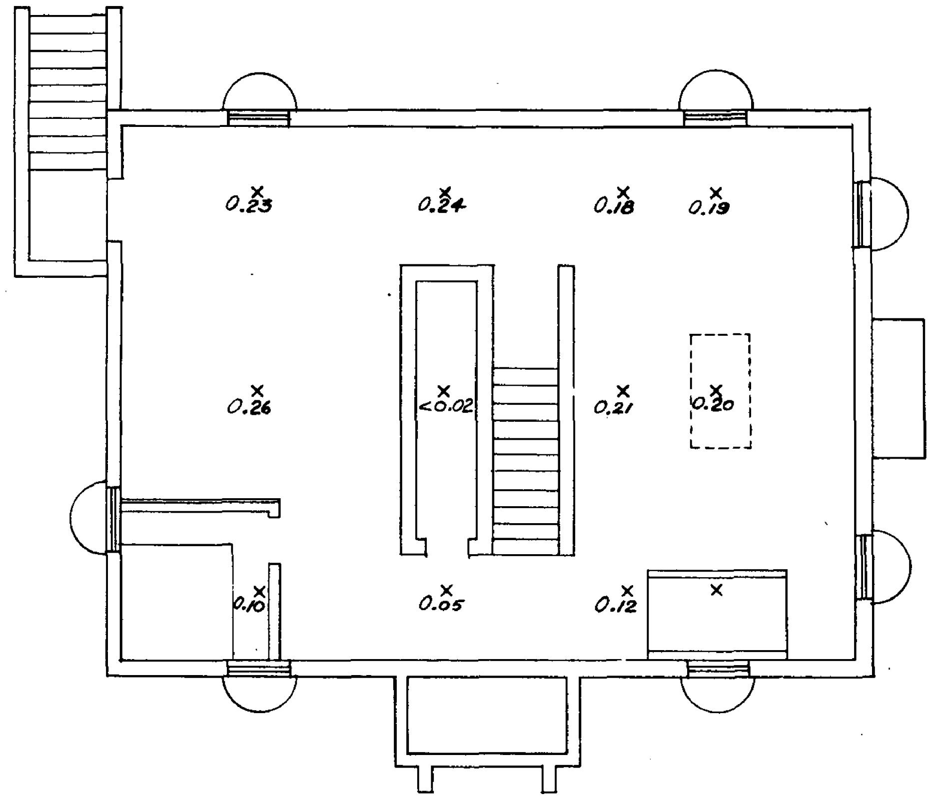

Fig. 3.51—2SWF house, 5-ft level, basement, sources in roof gutter (east).

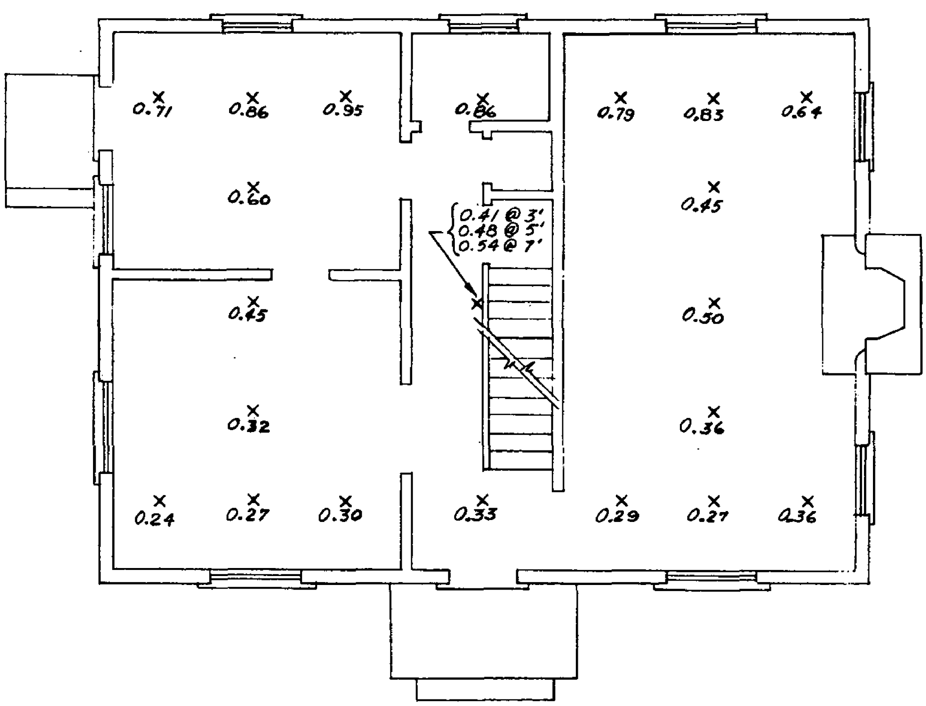

Fig. 3.52—2SWF house, 5-ft level, first floor, sources in roof gutter (east).

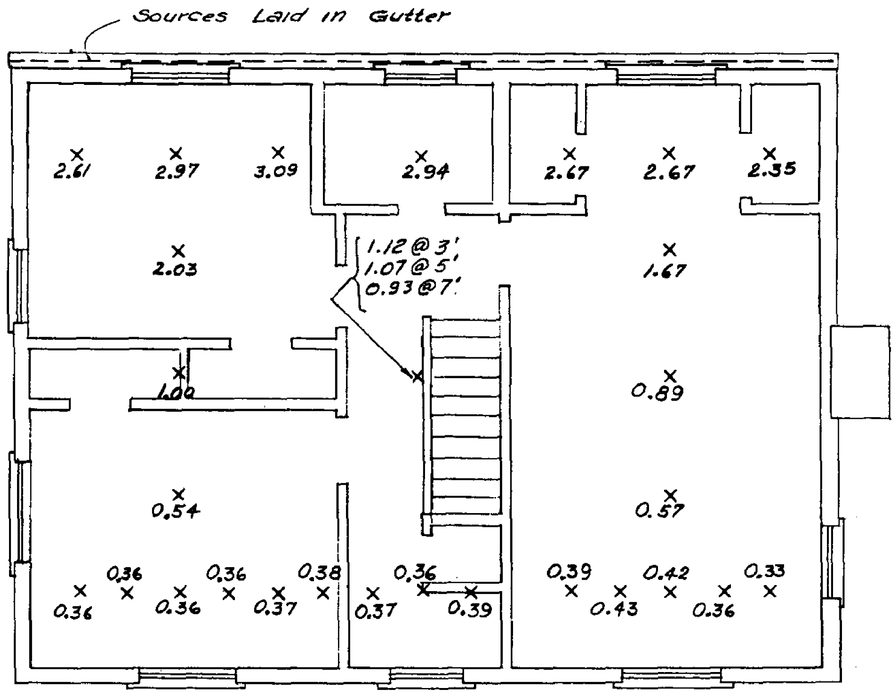

Fig. 3.53—2SWF house, 5-ft level, second floor, sources in roof gutter (east).

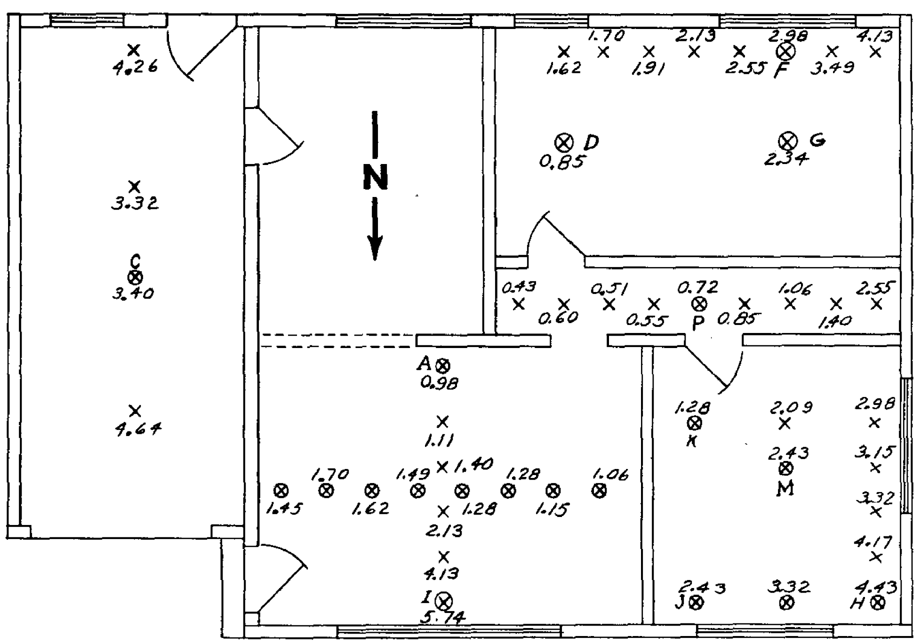

Fig. 3.54—PCC house, 3-ft level, ρ = 25.5 ft.

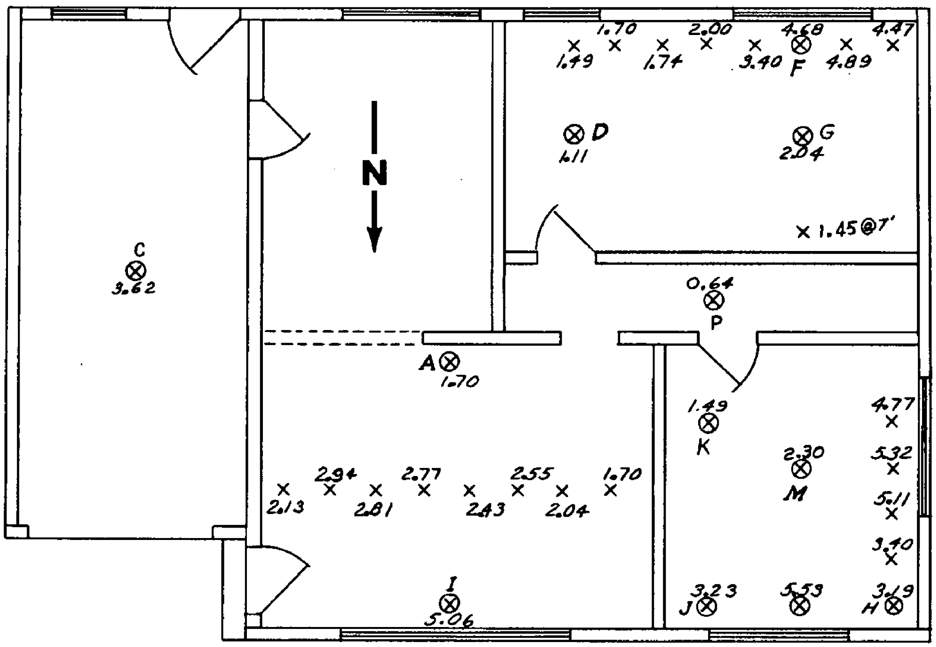

Fig. 3.55—PCC house, 5-ft level, ρ = 25.5 ft.

TABLE 3.37—VERTICAL TRAVERSES FOR THE PCC HOUSE FOR ρ = 25.5 FT

Position	1 ft	3 ft	5 ft	7 ft
A	0.43	0.98	1.70	1.91
C	1.15	3.40	3.62	3.15
D		0.85	1.11	1.02
F		2.98	4.68	5.11
G		2.34	2.04	2.34
H	7.23	4.43	3.19	2.38
I	1.91	5.74	5.06	5.11
I + 5 ft S + 1 ft E		1.49	2.77	2.68
I + 5 ft S + 3 ft E		1.62	2.81	2.77
I + 5 ft S + 5 ft E		1.70	2.94	2.64
I + 5 ft S + 7 ft E		1.45	2.13	2.00
I + 5 ft S + 1 ft W		1.28	2.43	2.55
I + 5 ft S + 3 ft W		1.28	2.55	2.30
I + 5 ft S + 5 ft W		1.15	2.04	1.96
I + 5 ft S + 7 ft W		1.06	1.70	1.70
J	1.45	2.43	3.23	
K	0.51	1.28	1.49	
M	0.98	2.43	2.30	
P	0.43	0.72	0.64	0.60

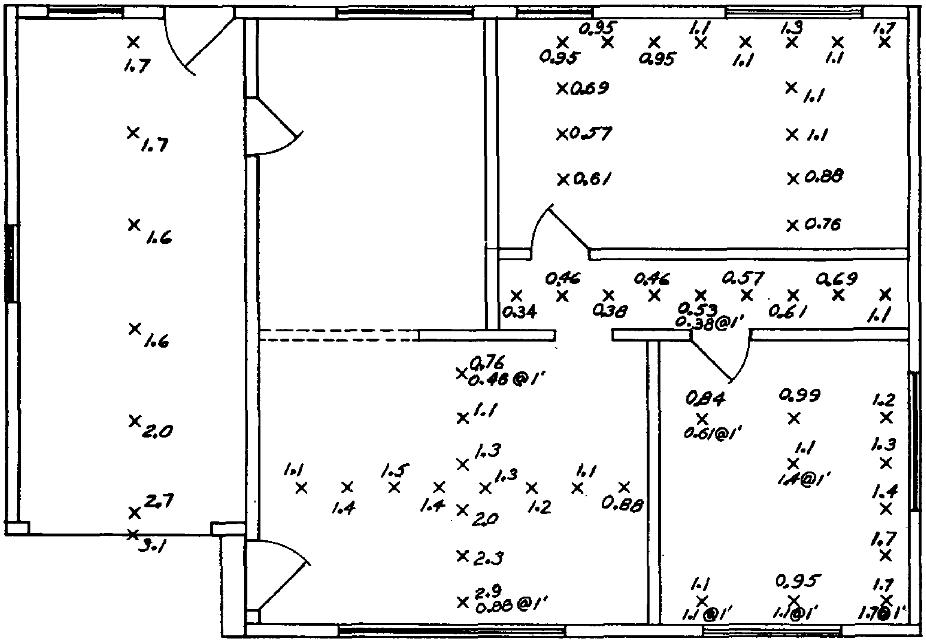

Fig. 3.56 — PCC house, 3-ft level, ρ = 42.5 ft.

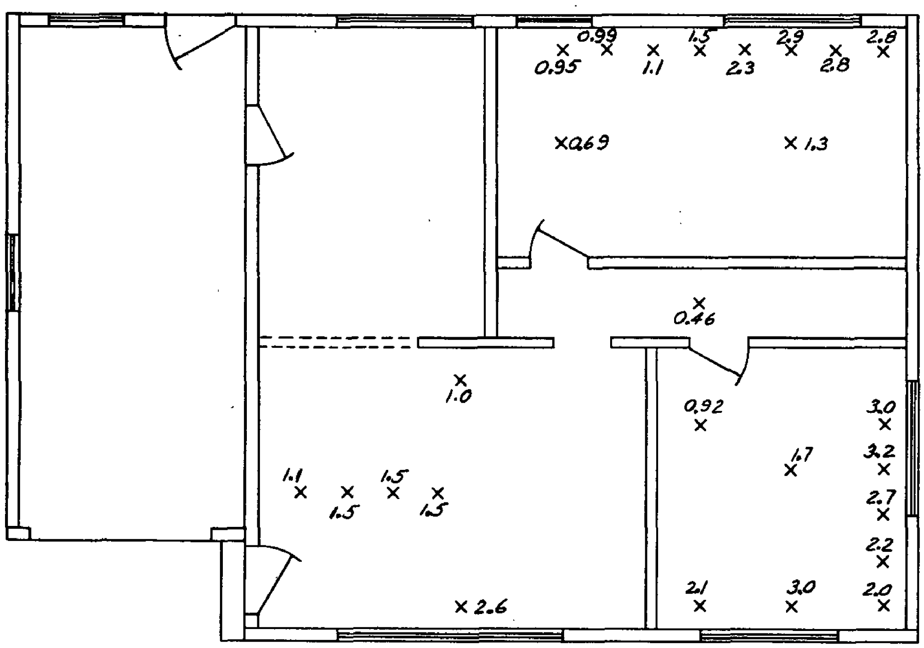

Fig. 3.57 — PCC house, 5-ft level, ρ = 42.5 ft.

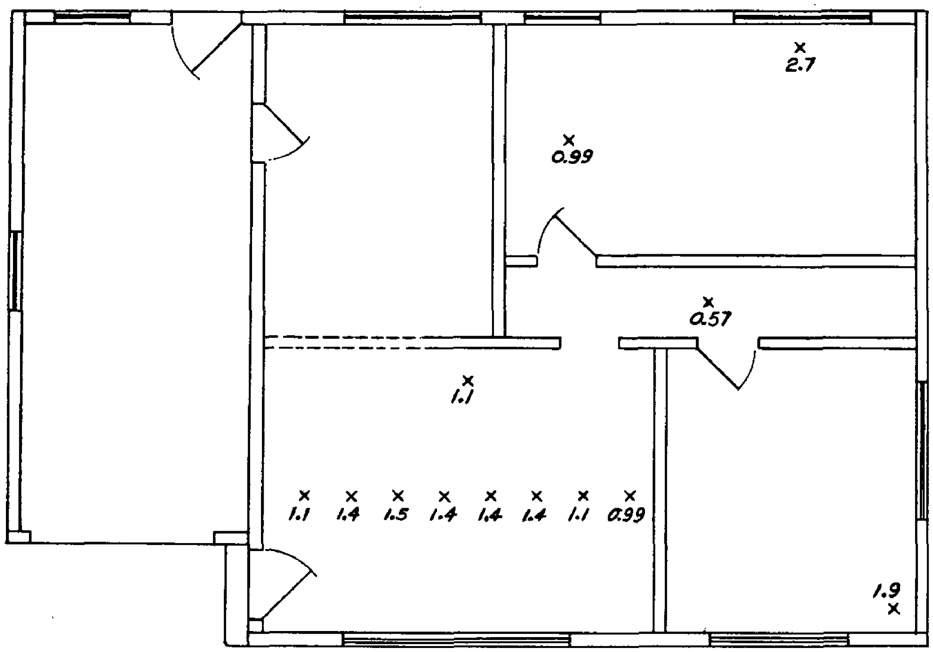

Fig. 3.58—PCC house, 7-ft level, ρ = 42.5 ft.

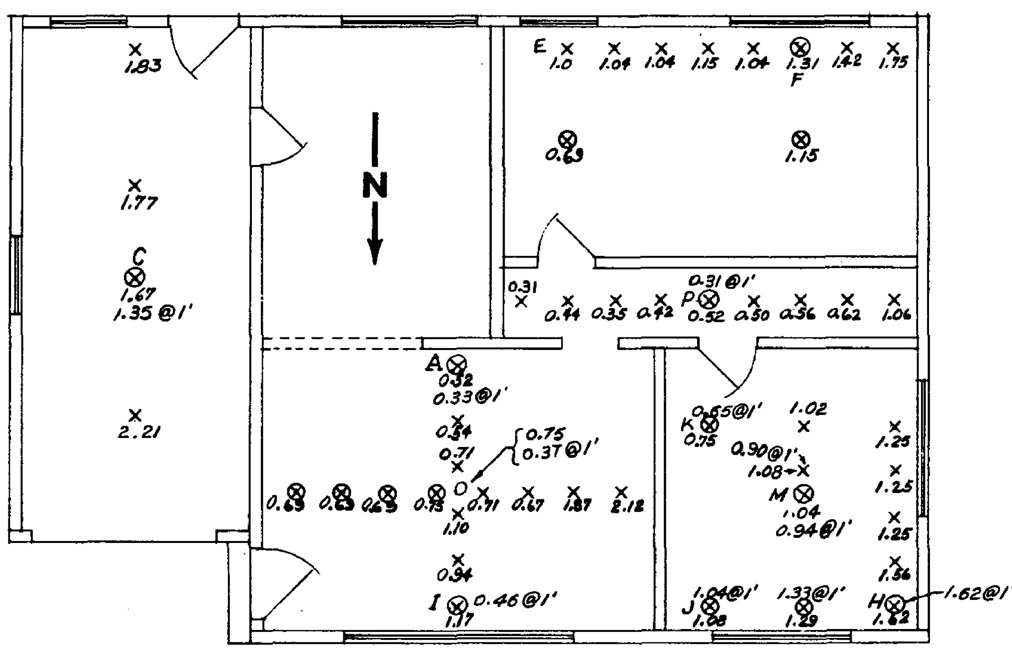

Fig. 3.59—PCC house, 3-ft level, ρ = 42.5 ft, concrete blocks in exterior openings of living room.

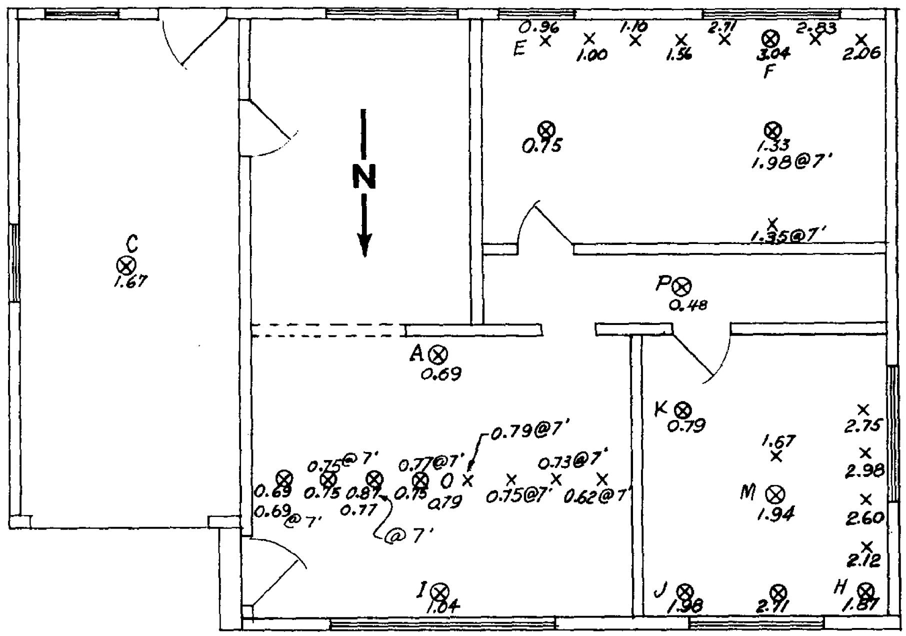

Fig. 3.60 — PCC house, 5-ft level, ρ = 42.5 ft, concrete blocks in exterior openings of living room.

TABLE 3.38 — VERTICAL TRAVERSES FOR THE PCC HOUSE (WITH CONCRETE BLOCKS IN EXTERIOR OPENINGS OF LIVING ROOM) FOR ρ = 42.5 FT

Position	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft
A	0.33		0.52		0.69		0.62	
C	1.35		1.67		1.67		2.29	
E + 4 ft N			0.69		0.75		1.25	
F			1.31		3.04		3.04	
F + 4 ft N			1.15		1.33		1.98	
H	1.62		1.62		1.87		1.83	
H + 4 ft E	1.33		1.29		2.71			
I	0.46		1.17		1.04		1.04	
J	1.04		1.08		1.98			
K	0.65		0.75		0.79			
M	0.94	1.04	1.04	1.06	1.94	2.29	2.29	2.29
O	0.37	0.52	0.75	0.75	0.79	0.79	0.79	0.79
O + 1 ft E			0.75		0.75		0.77	
O + 3 ft E			0.69		0.77		0.87	
O + 5 ft E			0.69		0.75		0.75	
O + 7 ft E			0.69		0.69		0.69	
P	0.31		0.52		0.48			

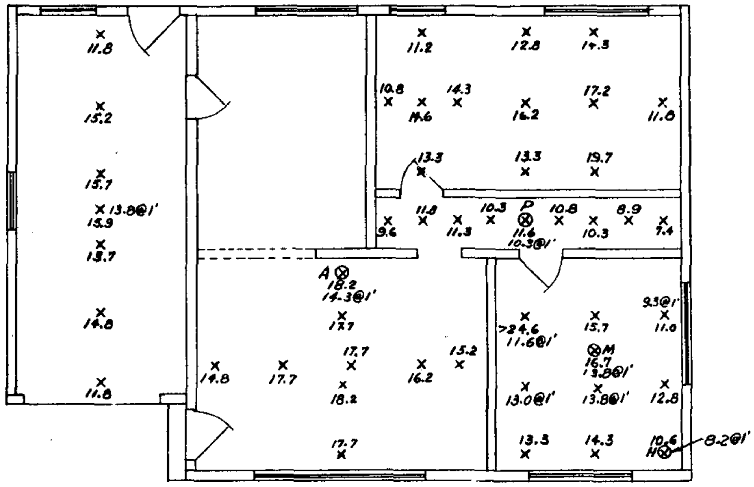

Fig. 3.61 — PCC house, 3-ft level, sources on roof. (All values should be multiplied by 1.12.)

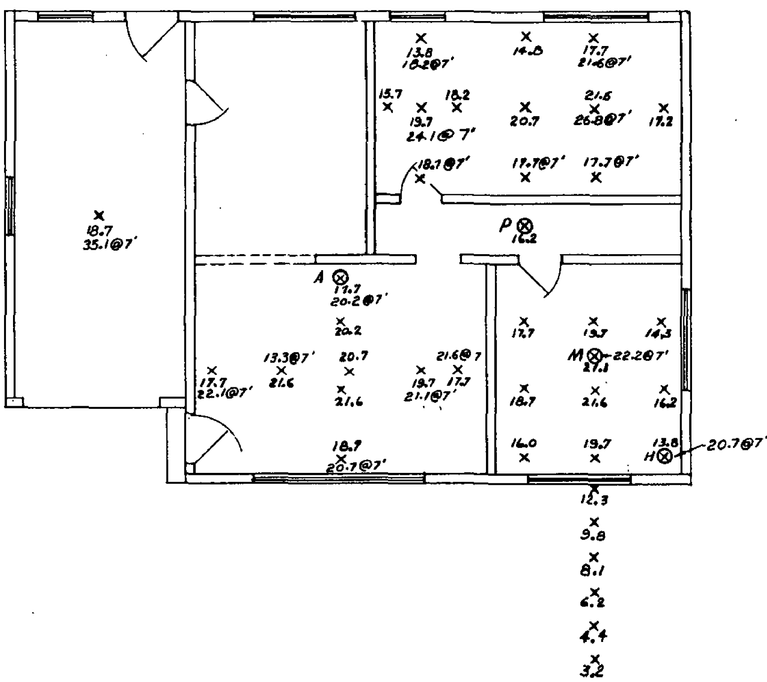

Fig. 3.62 — PCC house, 5-ft level, sources on roof. (All values should be multiplied by 1.12.)

TABLE 3.39 — VERTICAL TRAVERSES FOR THE PCC HOUSE FOR ROOF SOURCES*

Position	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft
A	14.3		18.2		17.7		20.2	
H	8.2		10.6		13.8		20.7	
M	13.8	15.7	16.7	19.2	21.1	20.7	22.2	38.4
P	10.3		11.6		16.2		20.2	

*All values should be multiplied by 1.12.

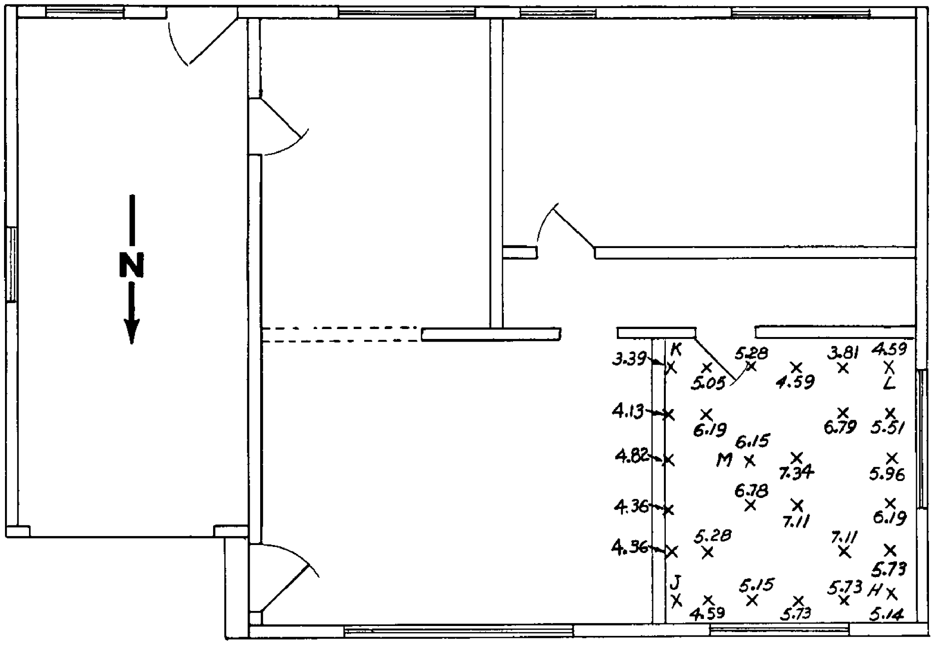

Fig. 3.63—PCC house, 1-ft level, sources on roof over northwest bedroom.

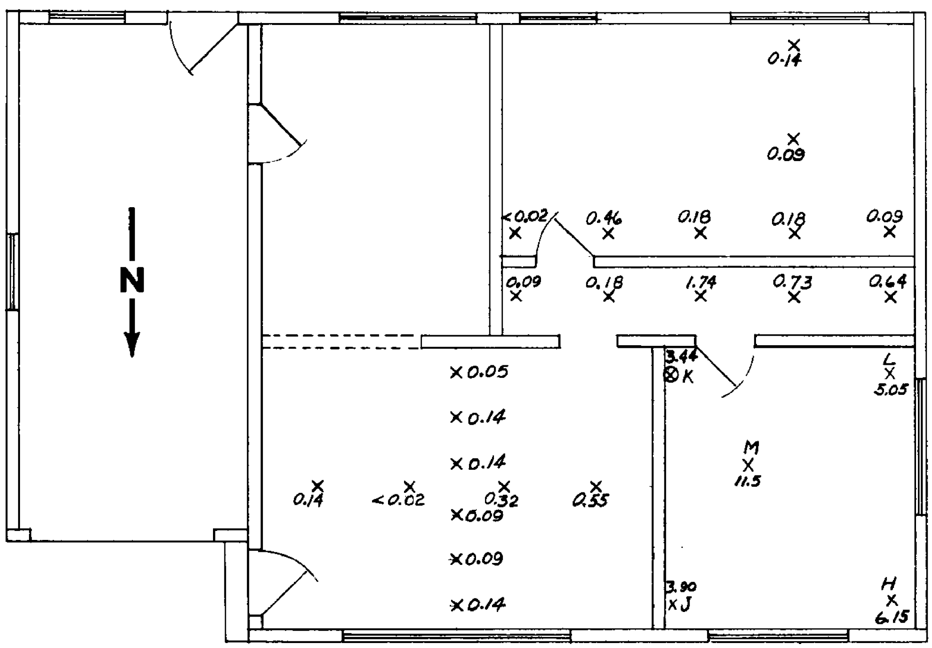

Fig. 3.64—PCC house, 3-ft level, sources on roof over northwest bedroom.

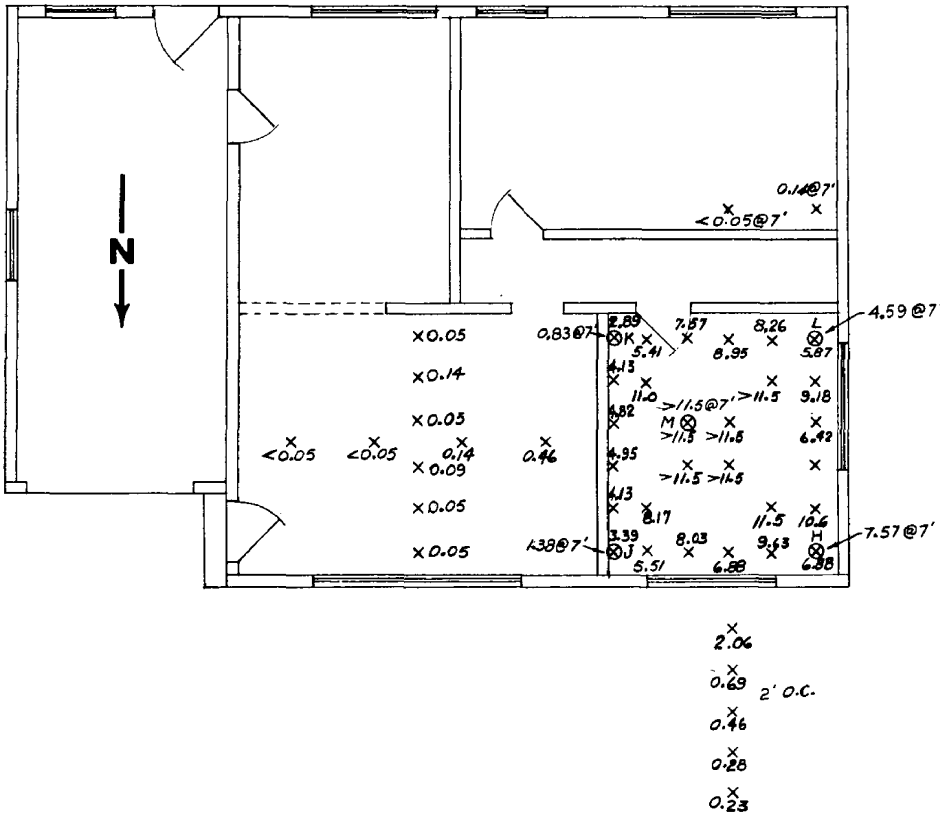

Fig. 3.65—PCC house, 5-ft level, sources on roof over northwest bedroom.

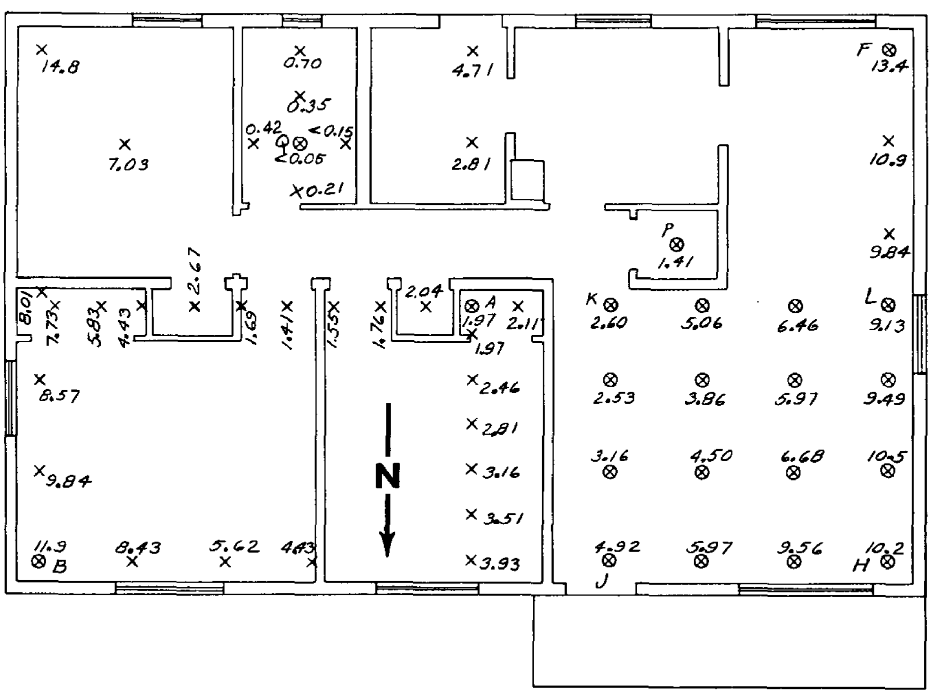

Fig. 3.66—Rambler house, 3-ft level, ρ = 25.5 ft.

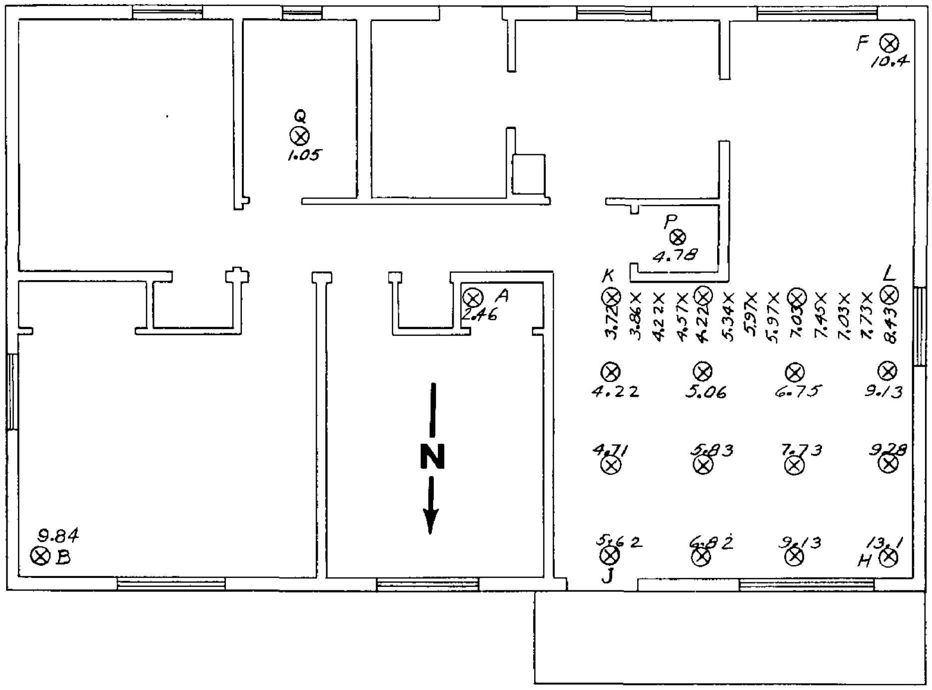

Fig. 3.67—Rambler house, 5-ft level, ρ = 25.5 ft.

TABLE 3.40—VERTICAL TRAVERSES FOR THE RAMBLER HOUSE FOR ρ = 25.5 FT

Position	1 ft	3 ft	5 ft	7 ft
A	0.42	1.97	2.46	3.02
B	14.1	11.9	9.84	7.03
F	14.8	13.4	10.4	
H	14.8	10.2	13.1	7.73
H + 4 ft E	4.08	9.56	9.13	
H + 4 ft S	10.5	10.5	9.28	
H + 4 ft S + 4 ft E	2.46	6.68	7.73	
J	4.22	4.92	5.62	
J + 4 ft W	4.64	5.97	6.82	
J + 4 ft S	1.55	3.16	4.71	
J + 4 ft S + 4 ft W	1.76	4.50	5.83	
K	0.35	2.60	3.72	
K + 4 ft N	0.56	2.53	4.22	
K + 4 ft W	0.70	5.06	4.22	
K + 4 ft N + 4 ft W	0.70	3.86	5.06	
L	8.93	9.13	8.43	
L + 4 ft N	17.2	9.49	9.13	
L + 4 ft E	0.84	6.46	7.03	
L + 4 ft E + 4 ft N	0.70	5.97	6.75	
P	0.49	1.41	4.78	4.57
Q	0.14	<0.05	1.05	1.05

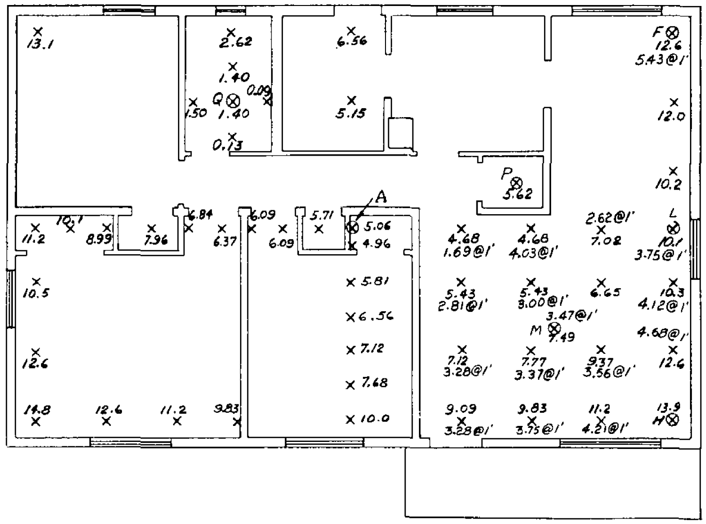

Fig. 3.68 — Rambler house, 3-ft level, $\rho = 42.5$ ft, concrete blocks 24 in. high along exterior walls of living-dining area. (All values should be multiplied by 0.333.)

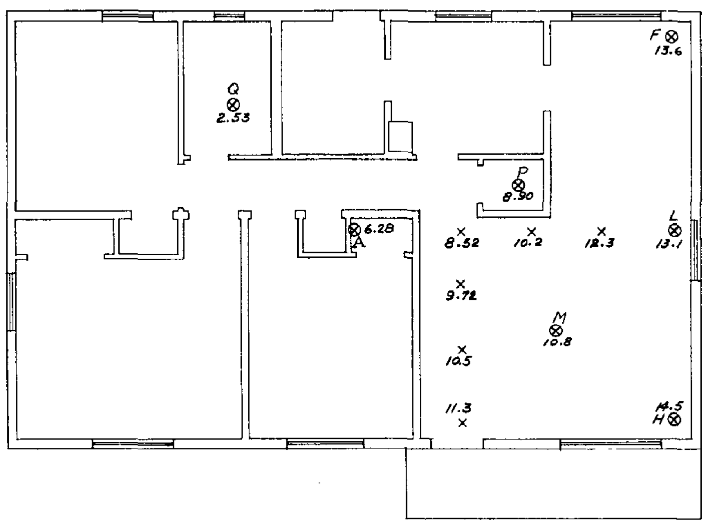

Fig. 3.69 — Rambler house, 5-ft level, $\rho = 42.5$ ft, concrete blocks 24 in. high along exterior walls of living-dining area. (All values should be multiplied by 0.333.)

TABLE 3.41 — VERTICAL TRAVERSES FOR THE RAMBLER HOUSE FOR $\rho = 42.5$ FT*

Position	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft
A	2.44	4.21	5.06	5.34	6.28	7.21	7.12	7.02
F	5.43		12.6		13.6		13.7	
H			13.9		14.5		13.6	
L	3.75		10.1		13.1		12.6†	
M	3.47	4.21	7.49	10.5	10.8	11.2	11.4	12.0
P	3.75		5.62		8.90		9.37	
Q	0.56		1.40		2.53		2.25	

*All values should be multiplied by 0.333.

†One foot south of other instruments in this traverse.

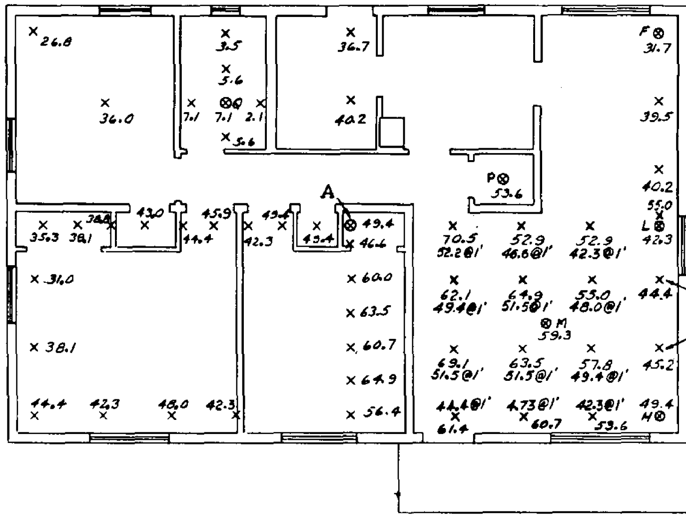

Fig. 3.70—Rambler house, 3-ft level, sources on roof.

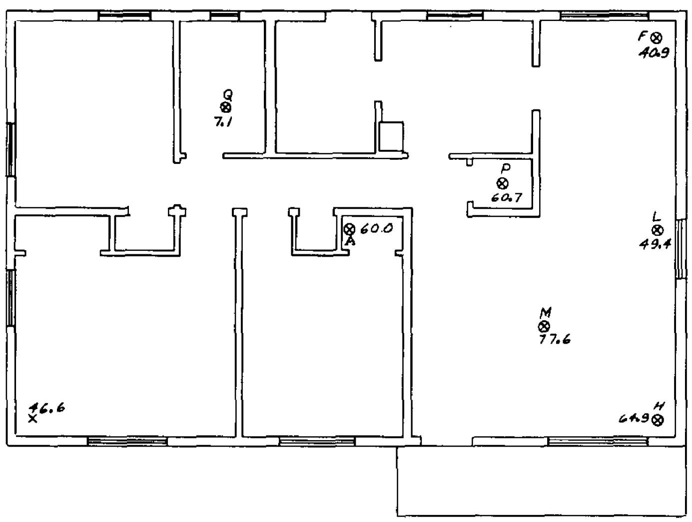

Fig. 3.71—Rambler house, 5-ft level, sources on roof.

TABLE 3.42—VERTICAL TRAVERSES FOR THE RAMBLER HOUSE FOR SOURCES ON THE ROOF

Position	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft
A	42.3	42.3	49.4	54.3	60	67	74.8	86.1
F	26.8		31.7		40.9		62.8	
H	41.6		49.4		64.9		88.9	
L	38.1		42.3		49.4		55.0	
M	50.8	58.6	59.3	67.0	77.6	84.7	97.4	109
P	42.3		53.6		60.7		81.1	
Q	4.2		7.1		7.1		4.2	

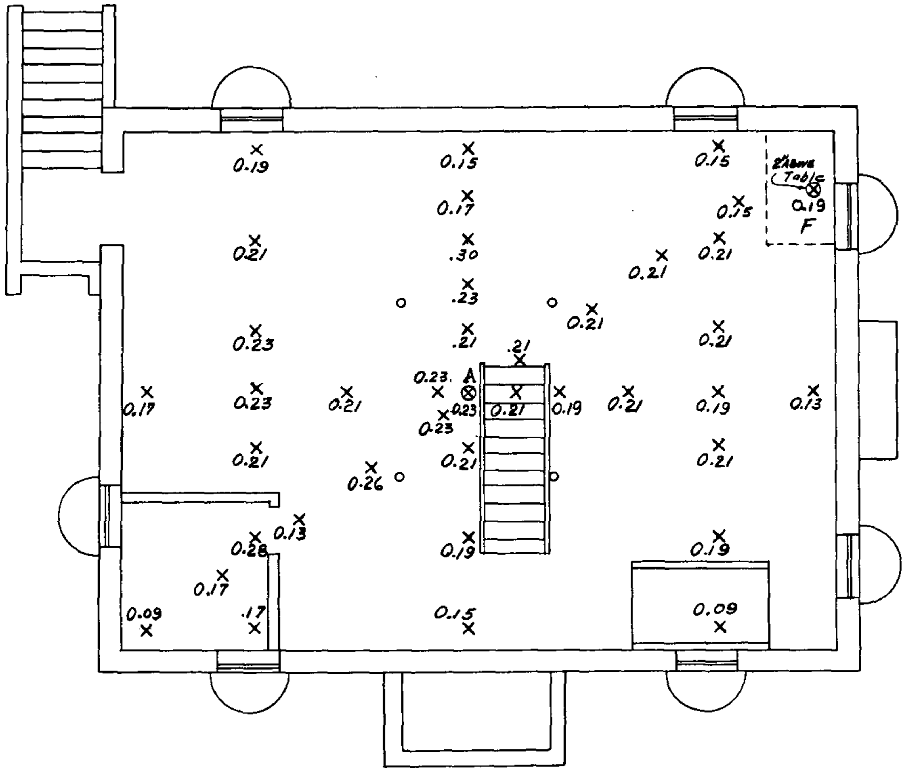

Fig. 3.72—2SB house, 3-ft level, basement, ρ = 25.5 ft, sandbags in four southernmost windows.

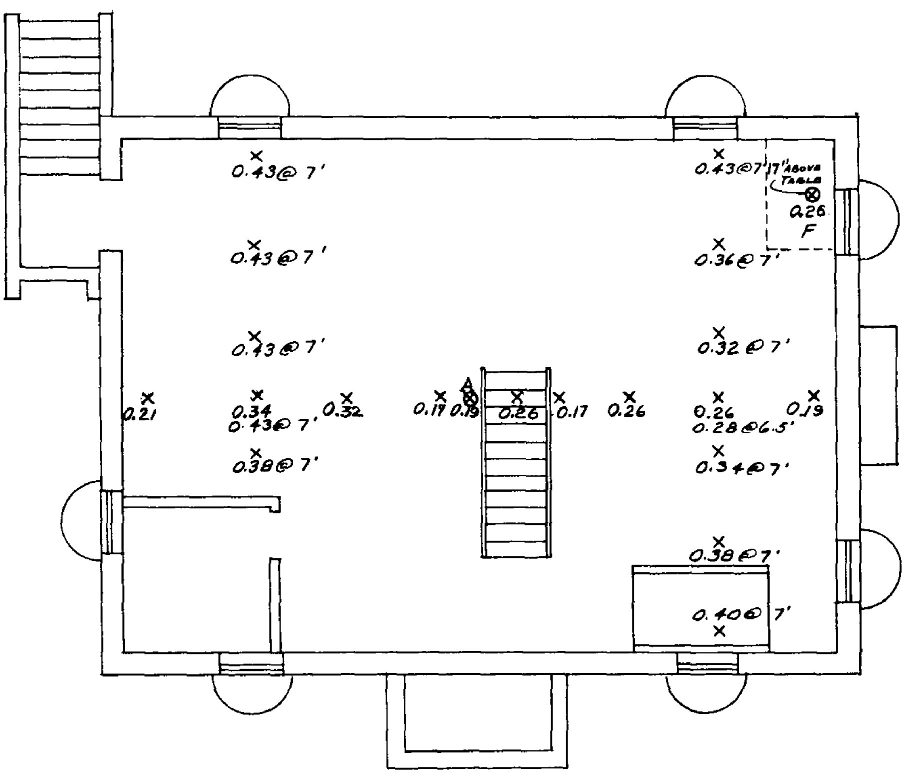

Fig. 3.73—2SB house, 5-ft level, basement, ρ = 25.5 ft, sandbags in four southernmost windows.

TABLE 3.43—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SB HOUSE FOR ρ = 25.5 FT

Position	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft
A	0.21	0.21	0.23	0.28	0.19	0.30	0.26
F	0.06	0.09	0.19*		0.26†		0.51

*Two inches above table top.
†Seventeen inches above table top.

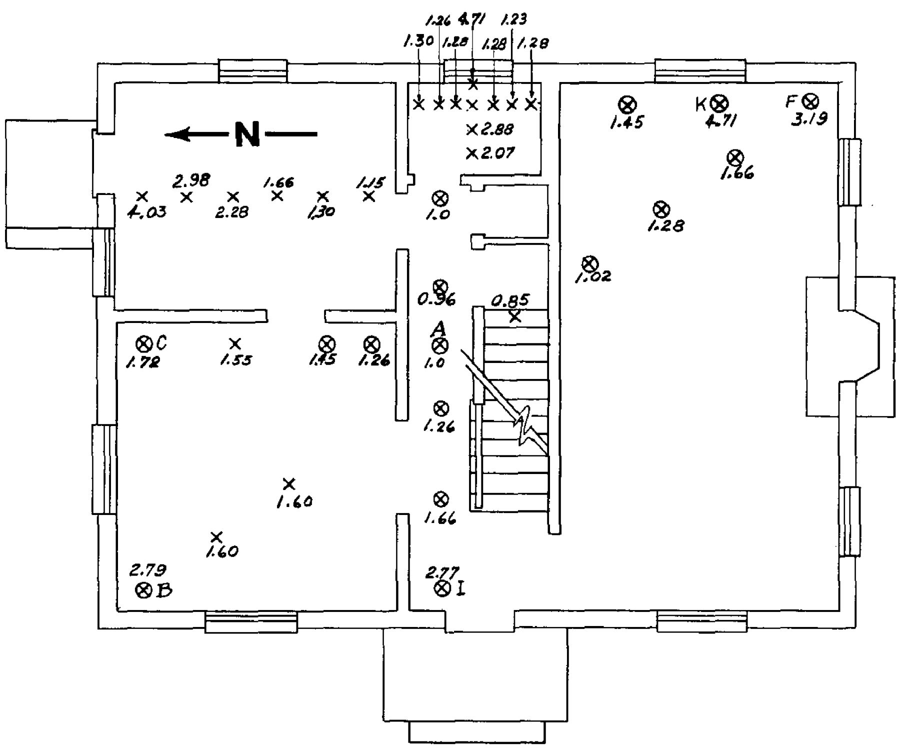

Fig. 3.74—2SB house, 3-ft level, first floor, ρ = 25.5 ft, sandbags in four southernmost basement windows.

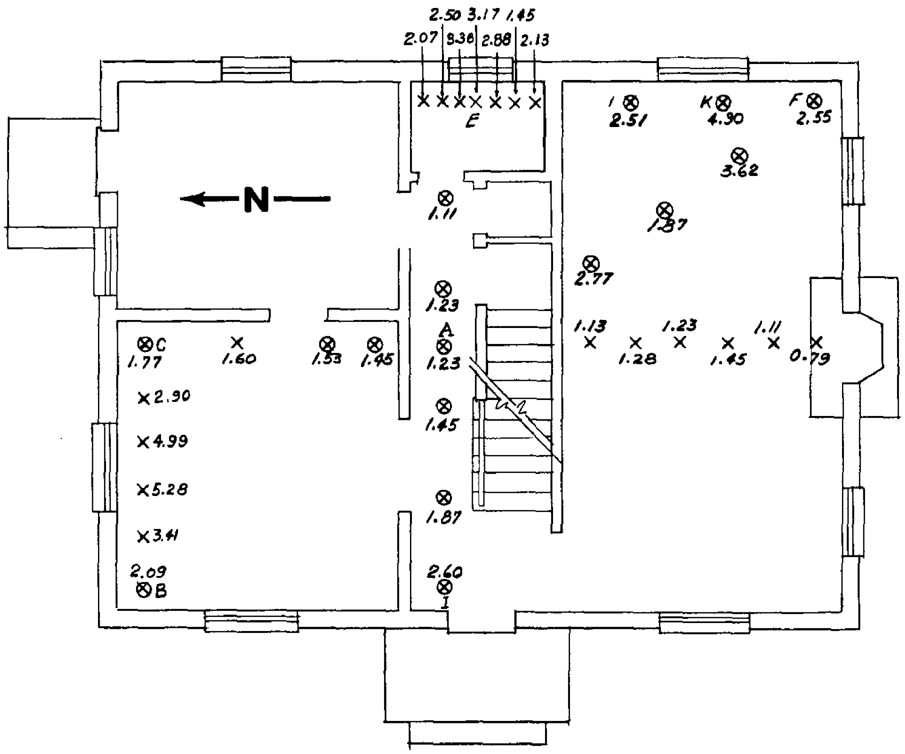

Fig. 3.75—2SB house, 5-ft level, first floor, ρ = 25.5 ft, sandbags in four southernmost basement windows.

TABLE 3.44—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SB HOUSE FOR ρ = 25.5 FT

Position	1 ft	3 ft	5 ft	7 ft
A	0.45	1.00	1.23	
A + 3 ft E	3.13	0.96	1.23	
A + 6 ft E	0.81	1.00	1.11	
A + 3 ft W	0.47	1.26	1.45	
A + 7 ft W	1.32	1.66	1.87	
A + 3 ft N	0.57	1.26	1.45	
A + 5 ft N	0.64	1.45	1.53	
B	3.15	2.79	2.09	1.60
C	1.53	1.72	1.77	2.28
F	3.07	3.19	2.55	
F + 4 ft NW	1.49	1.66	3.62	
F + 8 ft NW	0.81	1.28	1.87	
F + 12 ft NW	0.57	1.02	2.77	
I	2.53	2.77	2.60	
K	1.66	4.71	4.90	
K + 4 ft N	1.28	1.45	2.51	

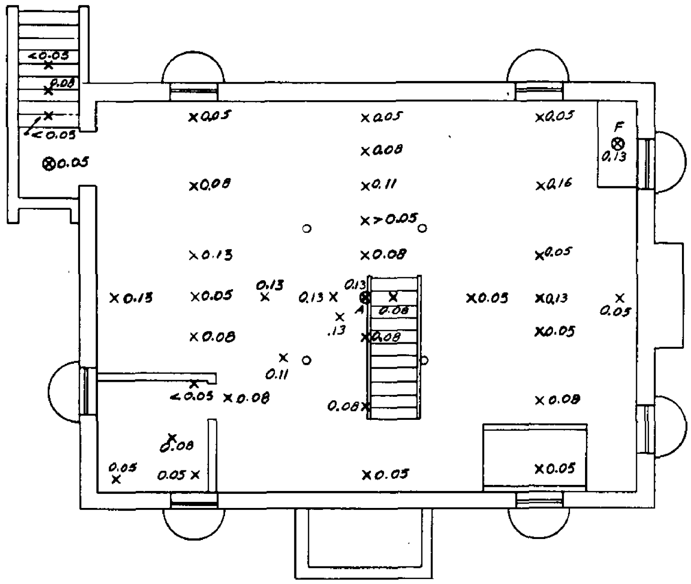

Fig. 3.76—2SB house, 3-ft level, basement, ρ = 42.5 ft, sandbags in four southernmost basement windows.

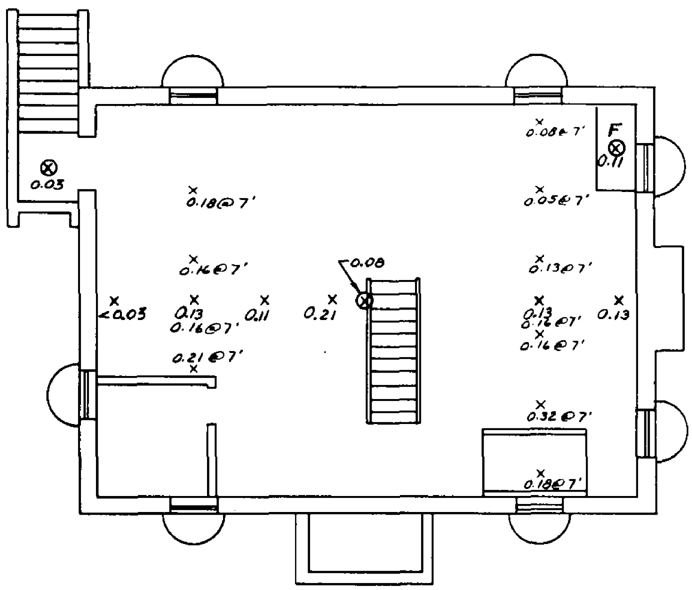

Fig. 3.77—2SB house, 5-ft level, basement, ρ = 42.5 ft, sandbags in four southernmost basement windows.

TABLE 3.45—VERTICAL TRAVERSES FOR THE BASEMENT OF THE 2SB HOUSE FOR ρ = 42.5 FT

Position	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft
A	0.11	0.11	0.13	0.11	0.08	0.11	0.16
F	<0.03	<0.03	0.13*		0.11		0.21
Entrance			0.05	0.05	0.03	0.13	0.42

*Two inches above concrete blocks on table top.

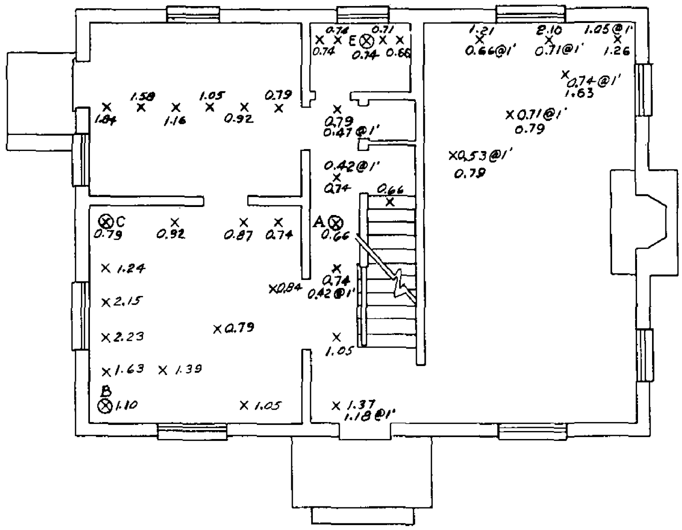

Fig. 3.78—2SB house, 3-ft level, first floor, ρ = 42.5 ft, sandbags in four southernmost basement windows.

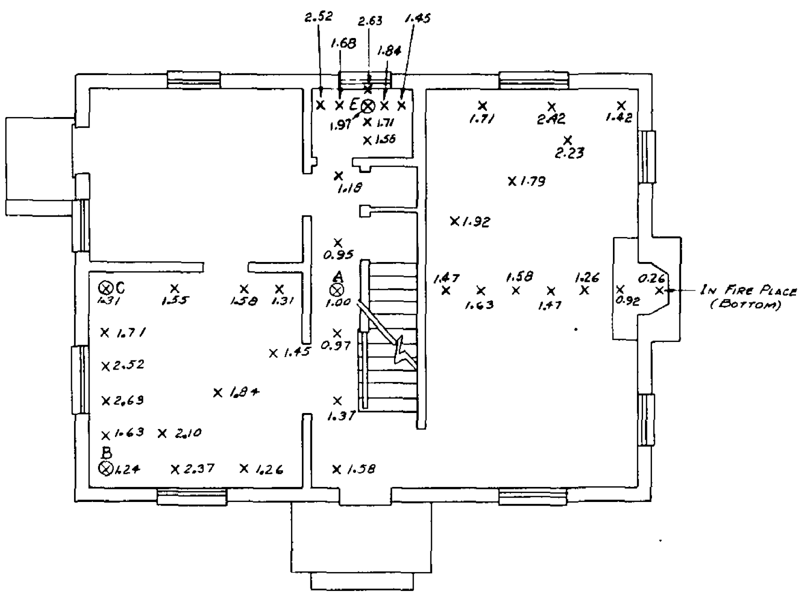

Fig. 3.79—2SB house, 5-ft level, first floor, ρ = 42.5 ft, sandbags in four southernmost basement windows.

TABLE 3.46—VERTICAL TRAVERSES FOR THE FIRST FLOOR OF THE 2SB HOUSE FOR ρ = 42.5 FT

Position	1 ft	3 ft	5 ft	7 ft
A	0.34	0.66	1.00	0.79
B	0.95	1.10	1.24	1.31
C	0.79	0.79	1.31	0.79
E		0.74	1.97	1.97

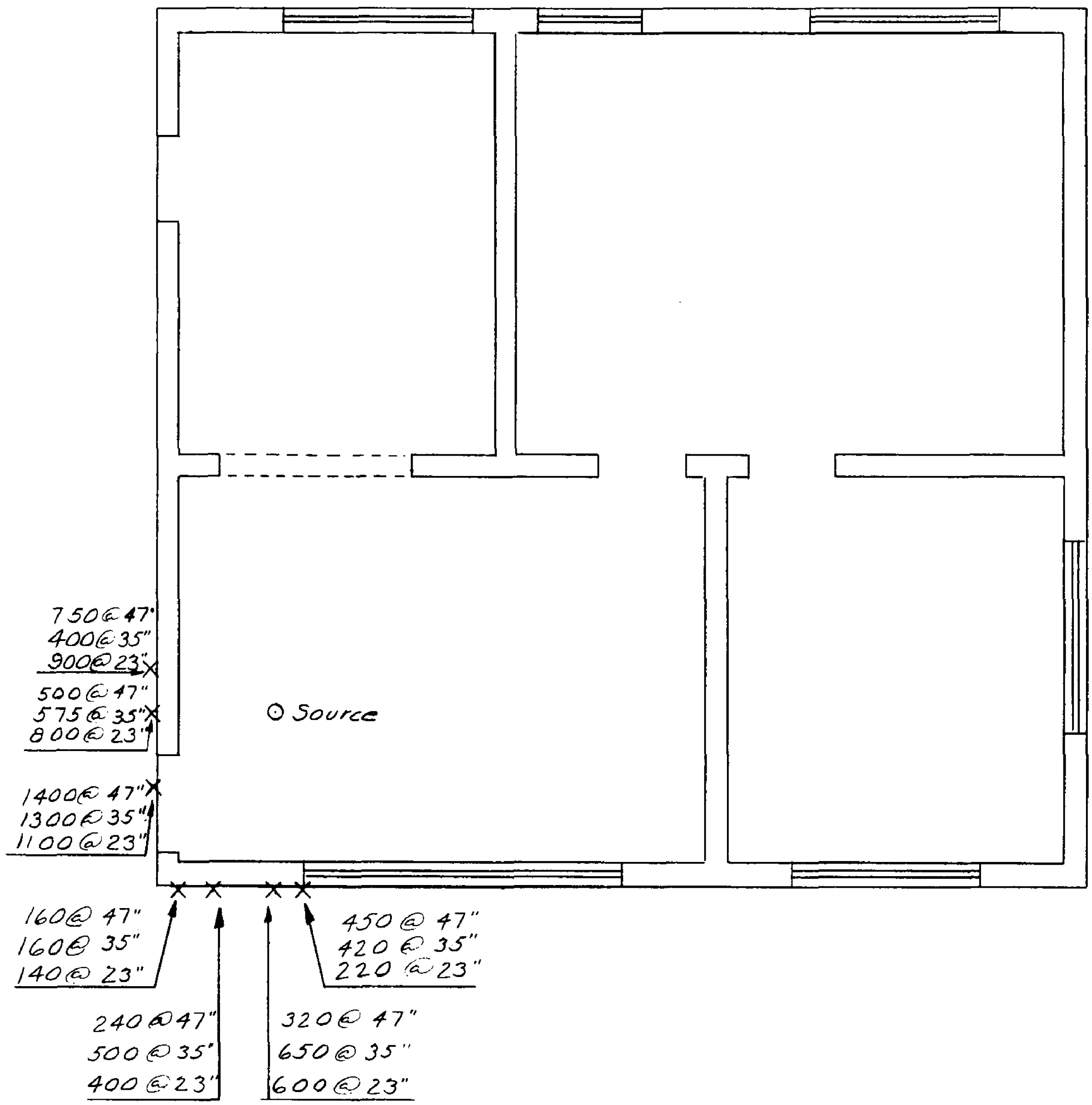

Fig. 3.80—RMB house, relative dose rate as a function of horizontal position and height above the floor; source height = 47 in.

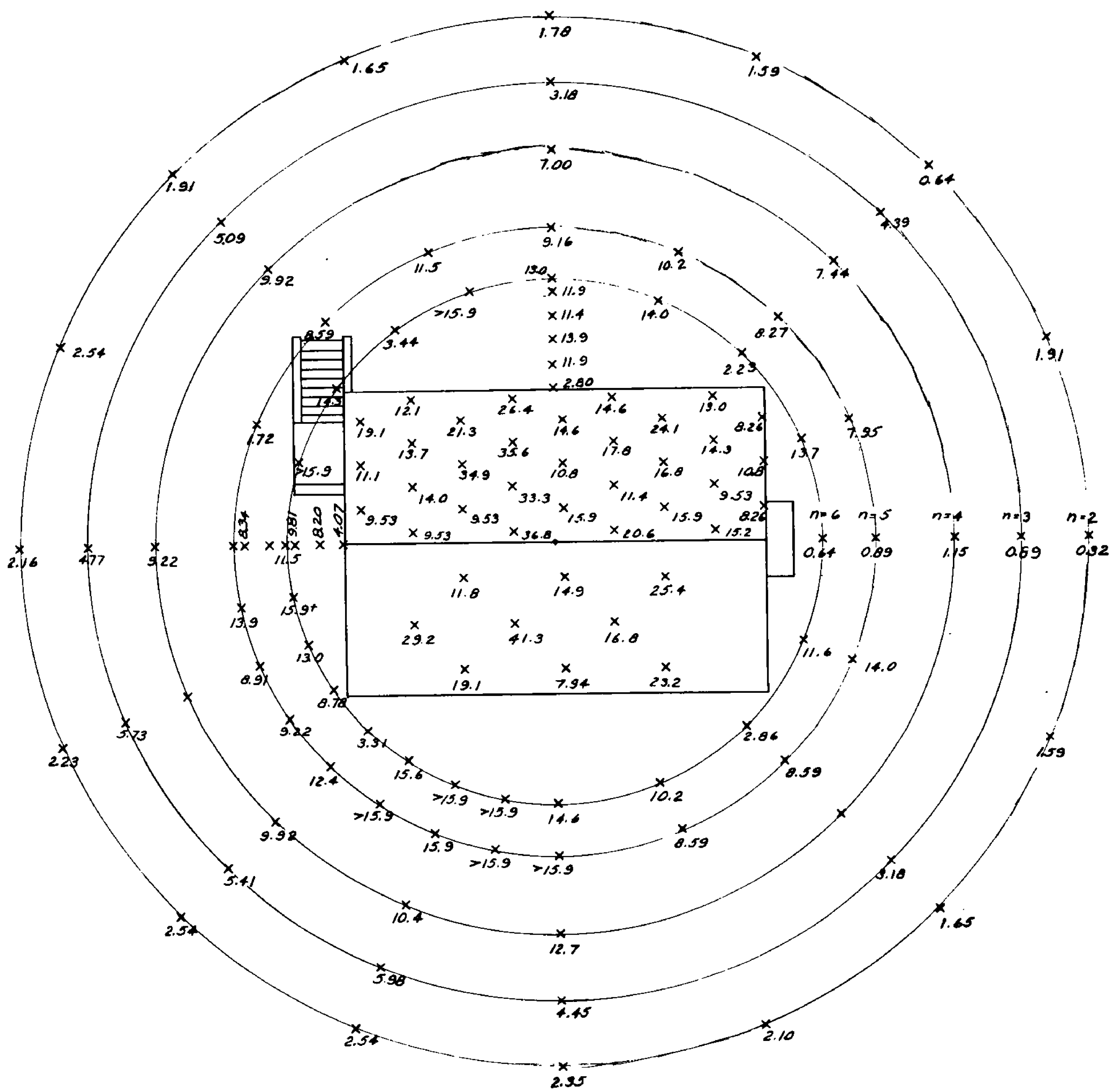

Fig. 3.81—2SWF house, reciprocity exposure, Co^{60} source 3 ft above first floor, center of house.

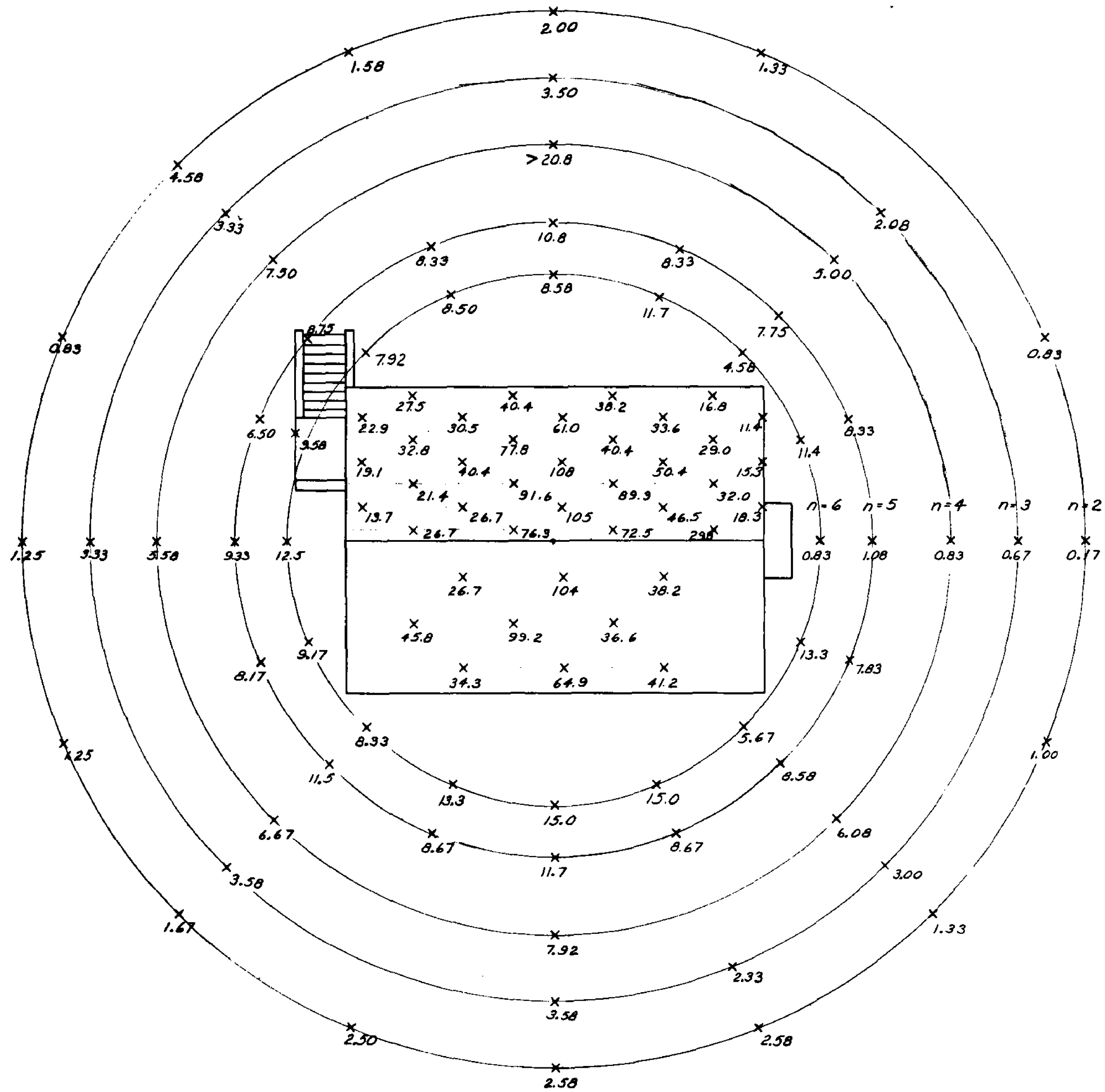

Fig. 3.82—2SWF house, reciprocity exposure, Co^{60} source 3 ft above second floor, center of house.

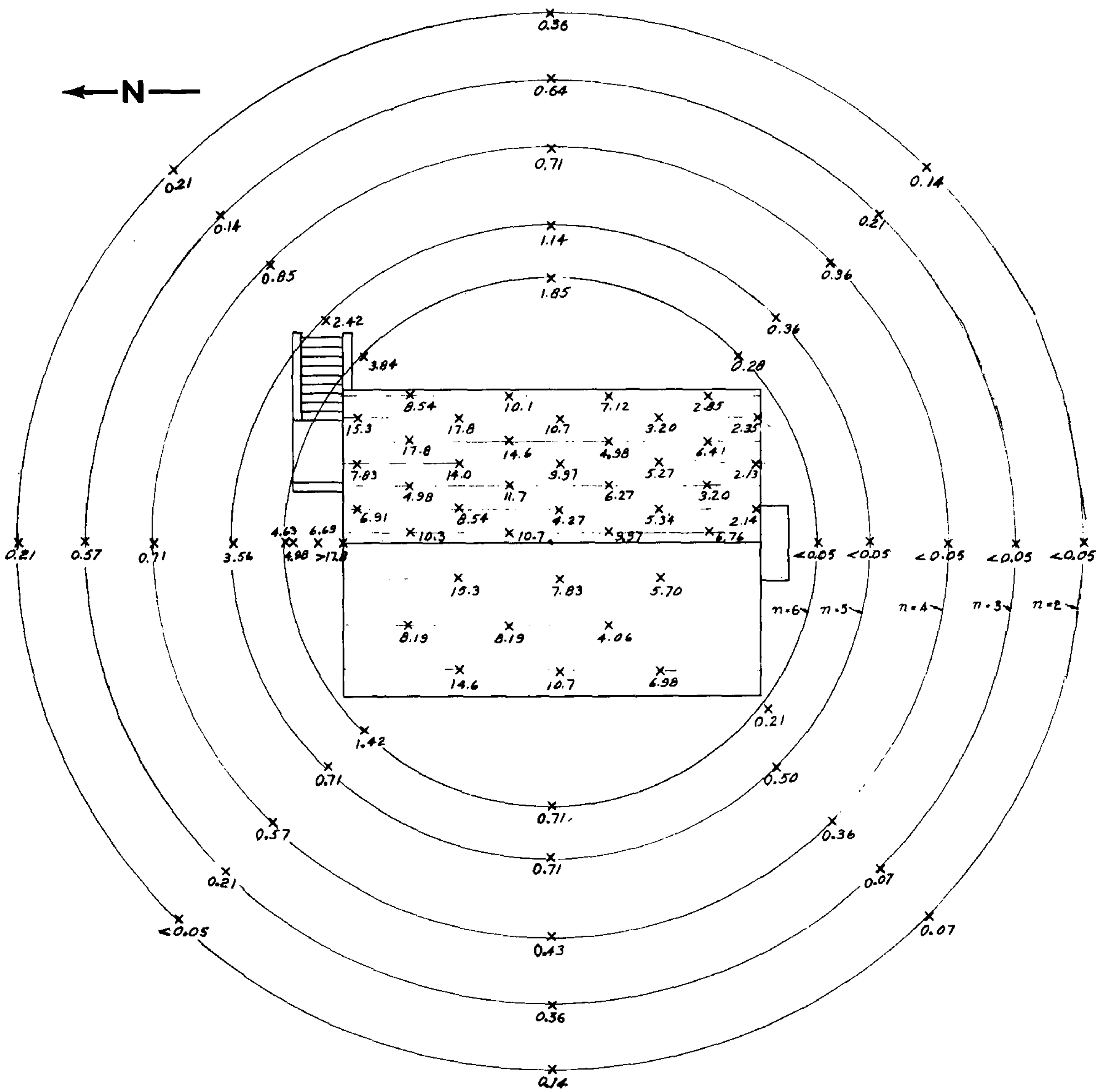

Fig. 3.83—2SWF house, reciprocity exposure, Co^{60} source 3 ft above floor at center of north area of basement.

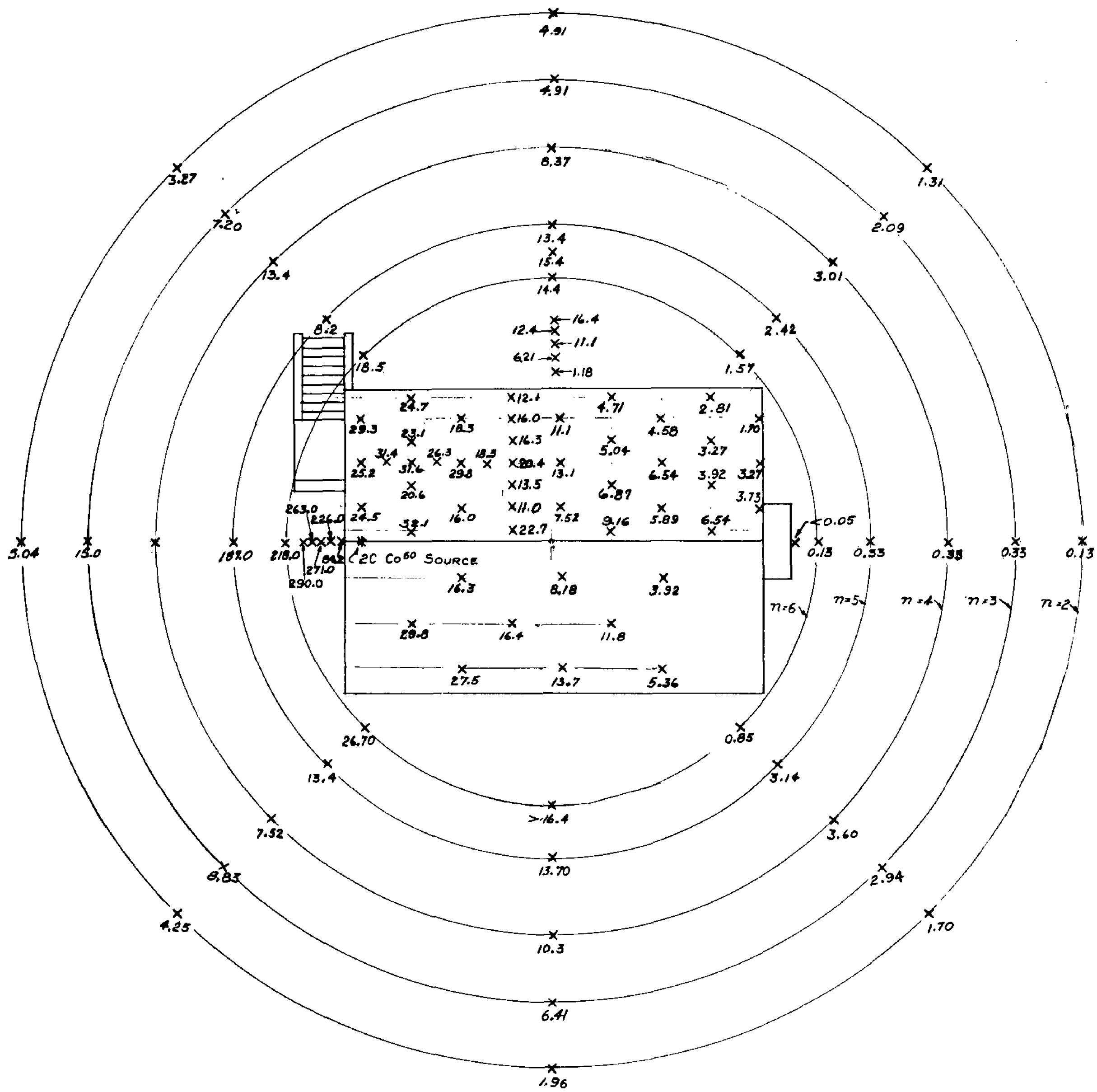

Fig. 3.84—2SWF house, reciprocity exposure, Co^{60} source 3 ft above first floor, 1 ft from north end at center of house.

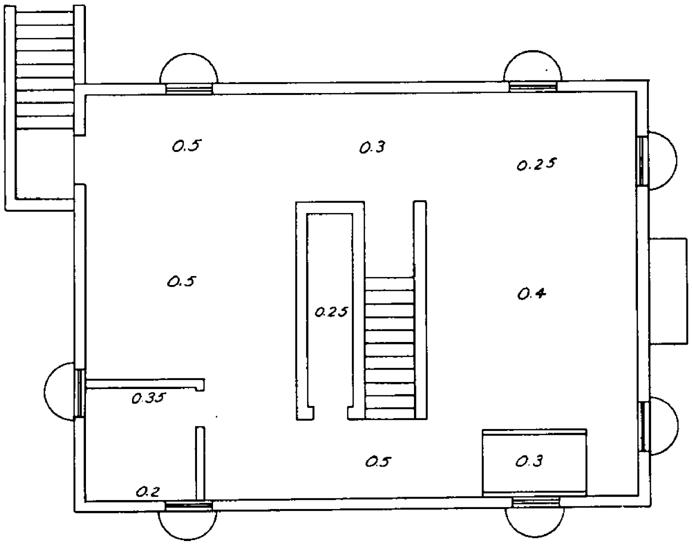

Fig. 3.85—2SWF house, survey instrument readings, 3 ft above basement floor, 8.4-millicurie Co^{60} source 3 ft above center of first floor.

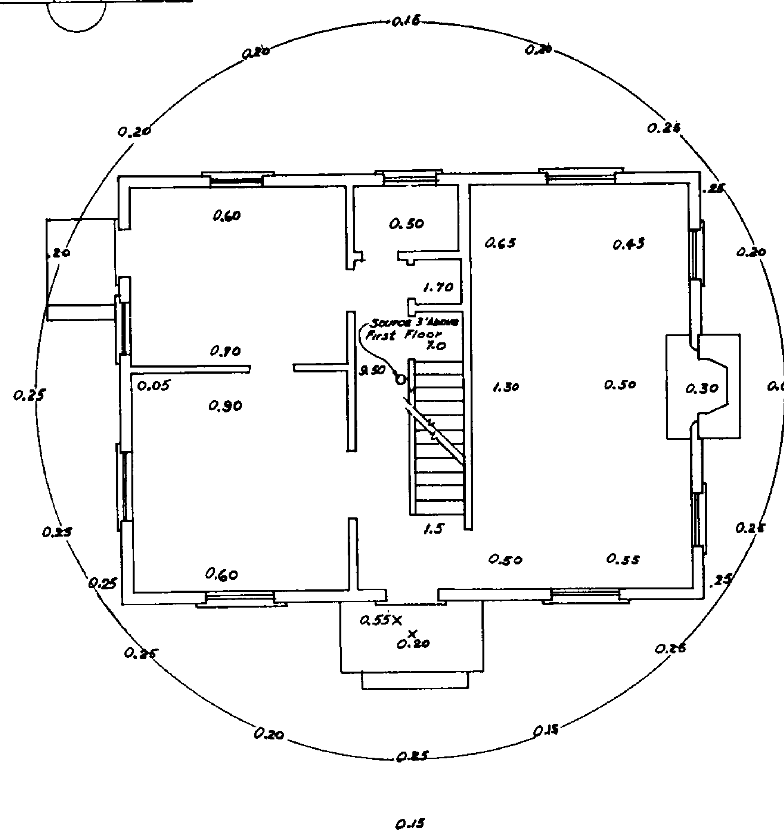

Fig. 3.86—2SWF house, survey instrument readings, 3 ft above first floor and 1 in. above ground, 8.4-millicurie Co^{60} source 3 ft above center of first floor.

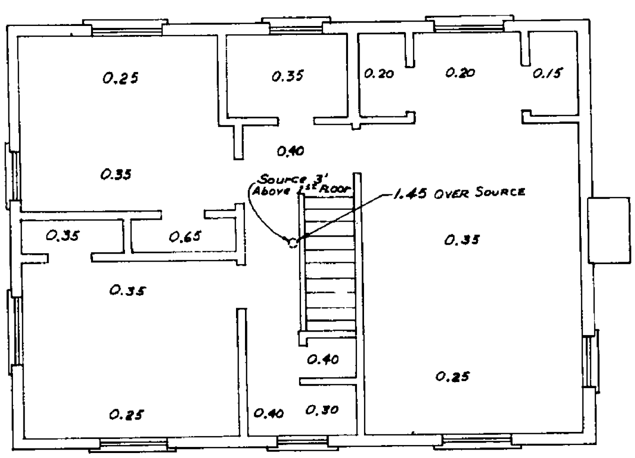

Fig. 3.87—2SWF house, survey instrument readings, 3 ft above second floor, 8.4-millicurie Co^{60} source 3 ft above center of first floor.

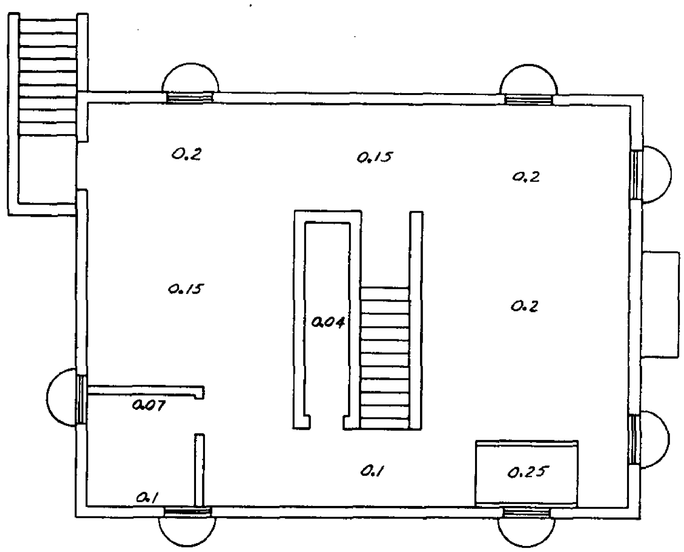

Fig. 3.88—2SWF house, survey instrument readings, 3 ft above basement floor, 8.4-millicurie Co^{60} source 3 ft above center of second floor.

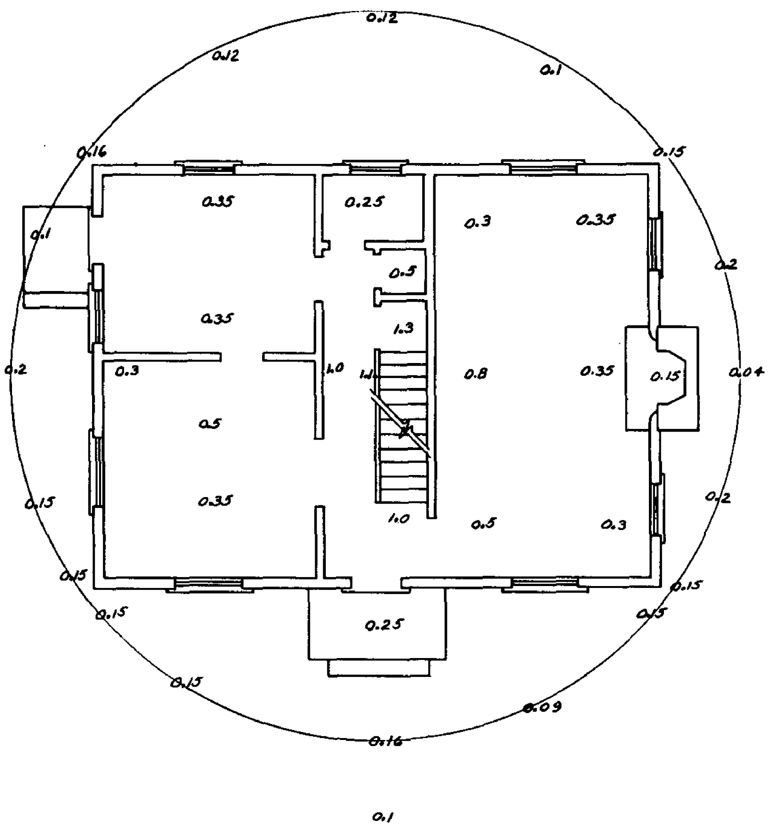

Fig. 3.89—2SWF house, survey instrument readings, 3 ft above first floor and 1 in. above ground, 8.4-millicurie Co^{60} source 3 ft above center of second floor.

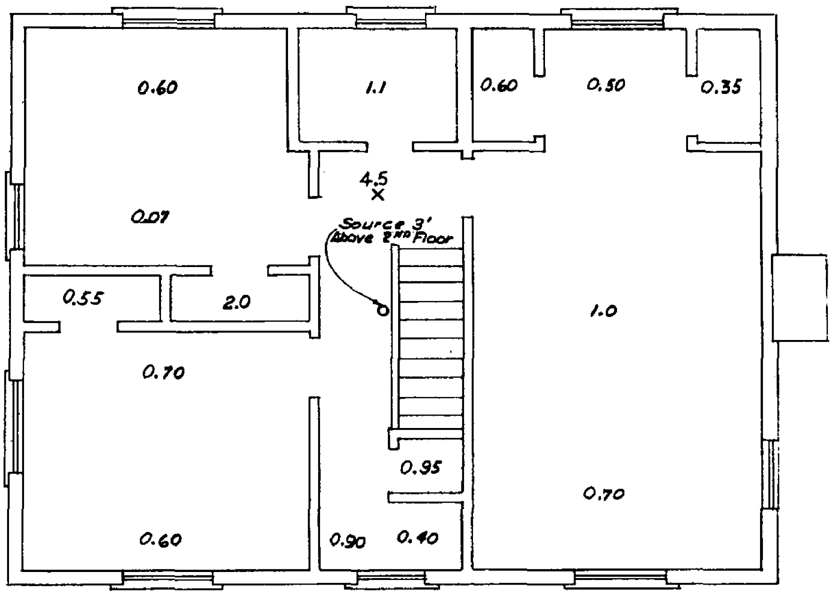

Fig. 3.90—2SWF house, survey instrument readings, 3 ft above second floor, 8.4-millicurie Co^{60} source 3 ft above center of second floor.

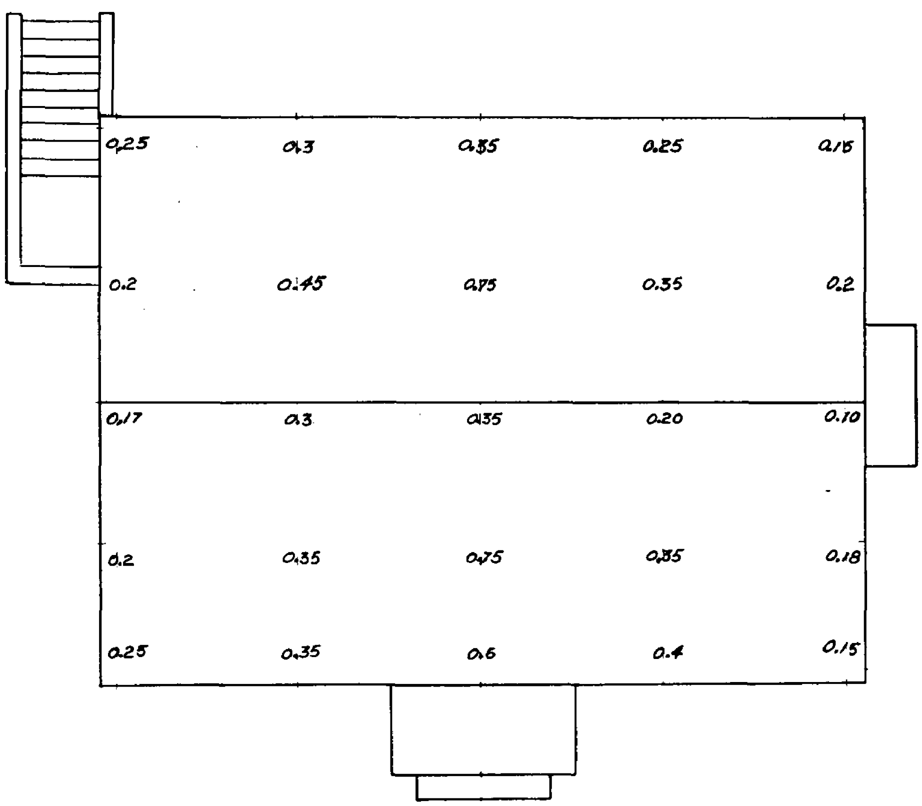

Fig. 3.91—2SWF house, survey instrument readings, 1 in. above roof, 8.4-millicurie Co^{60} source 3 ft above center of second floor.

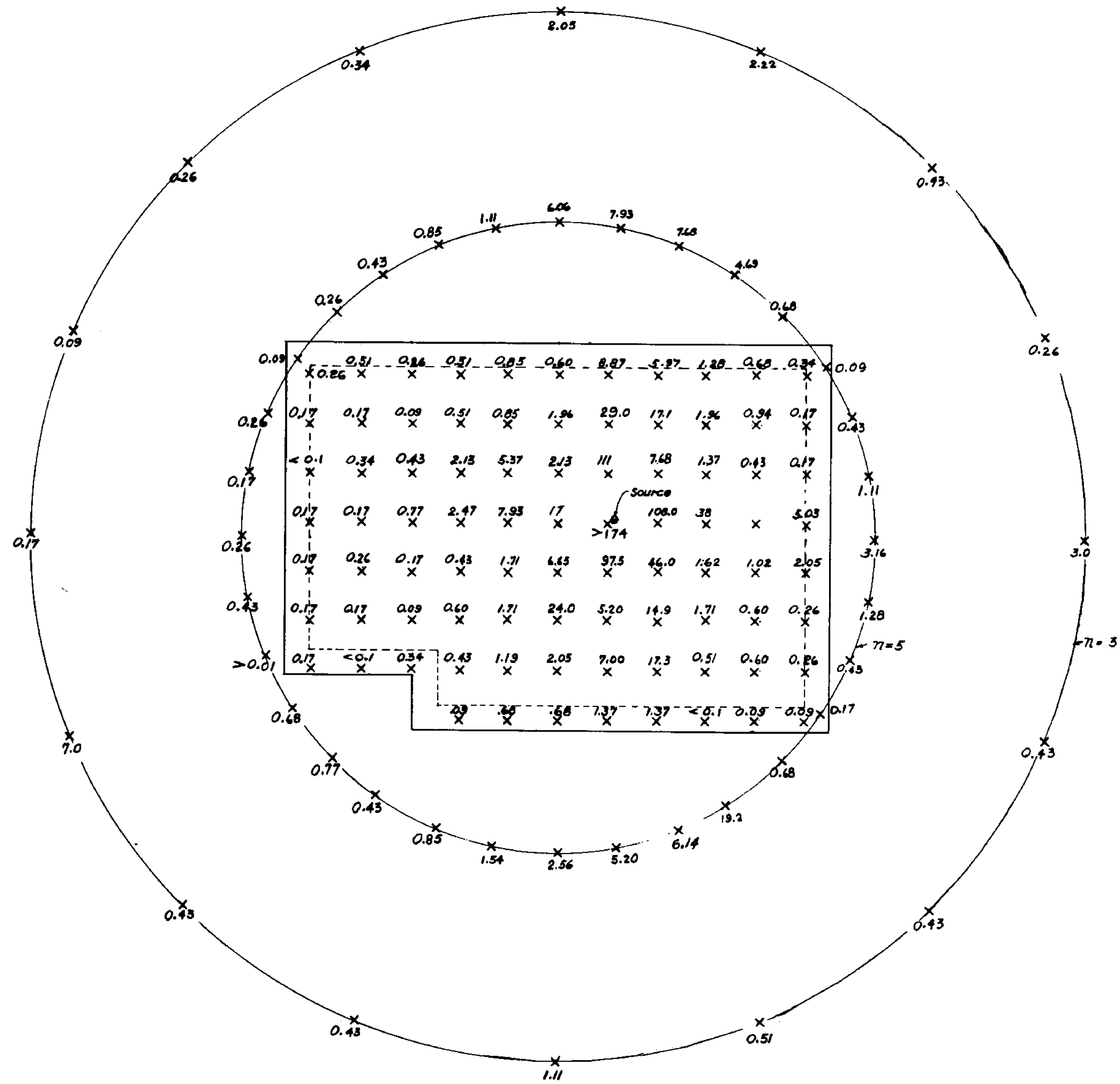

Fig. 3.92—PCC house, reciprocity exposure, source 3 ft above floor at point near center of house.

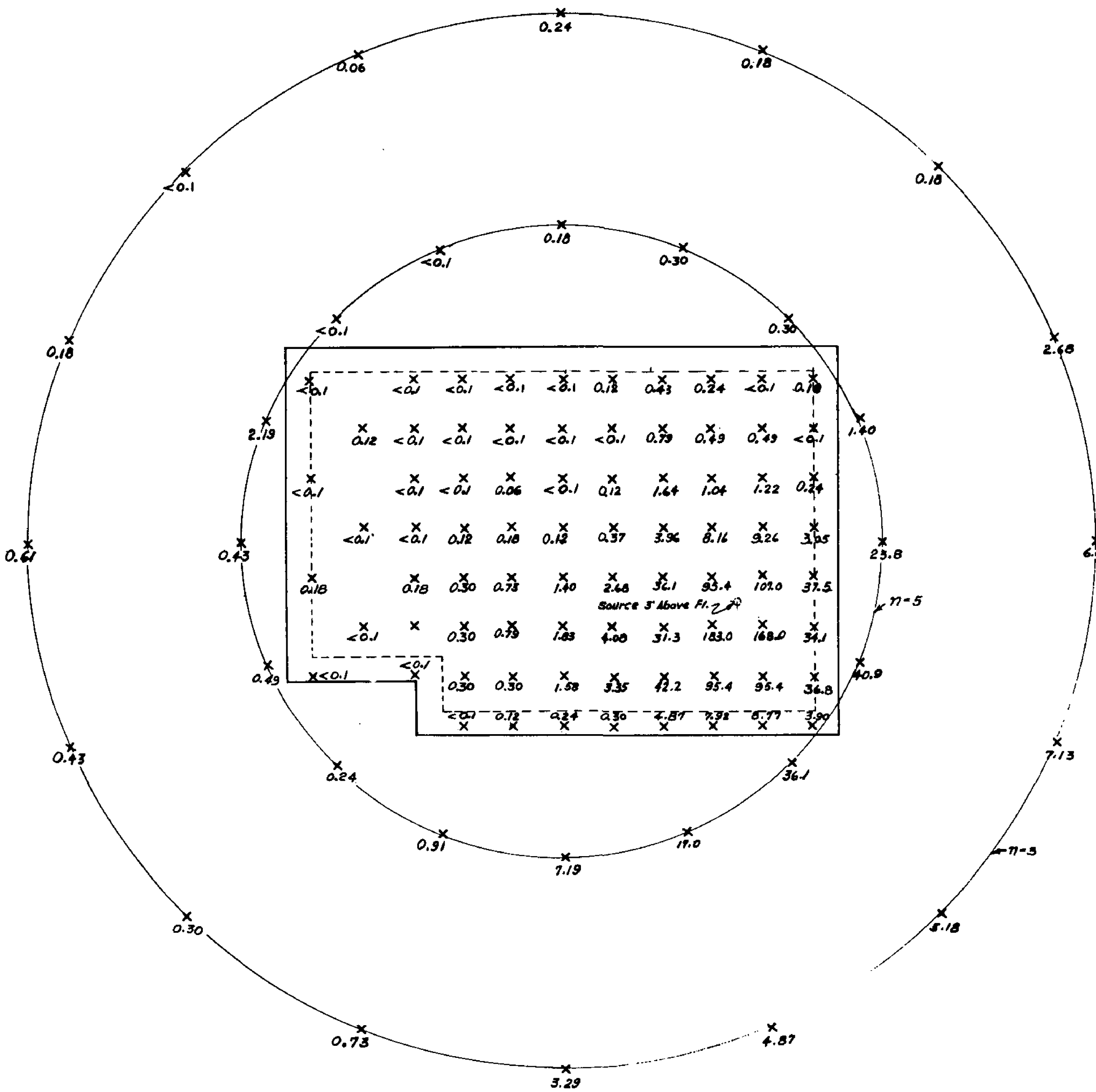

Fig. 3.93—PCC house, reciprocity exposure, 2.1-curie source 3 ft above center of northwest bedroom floor.

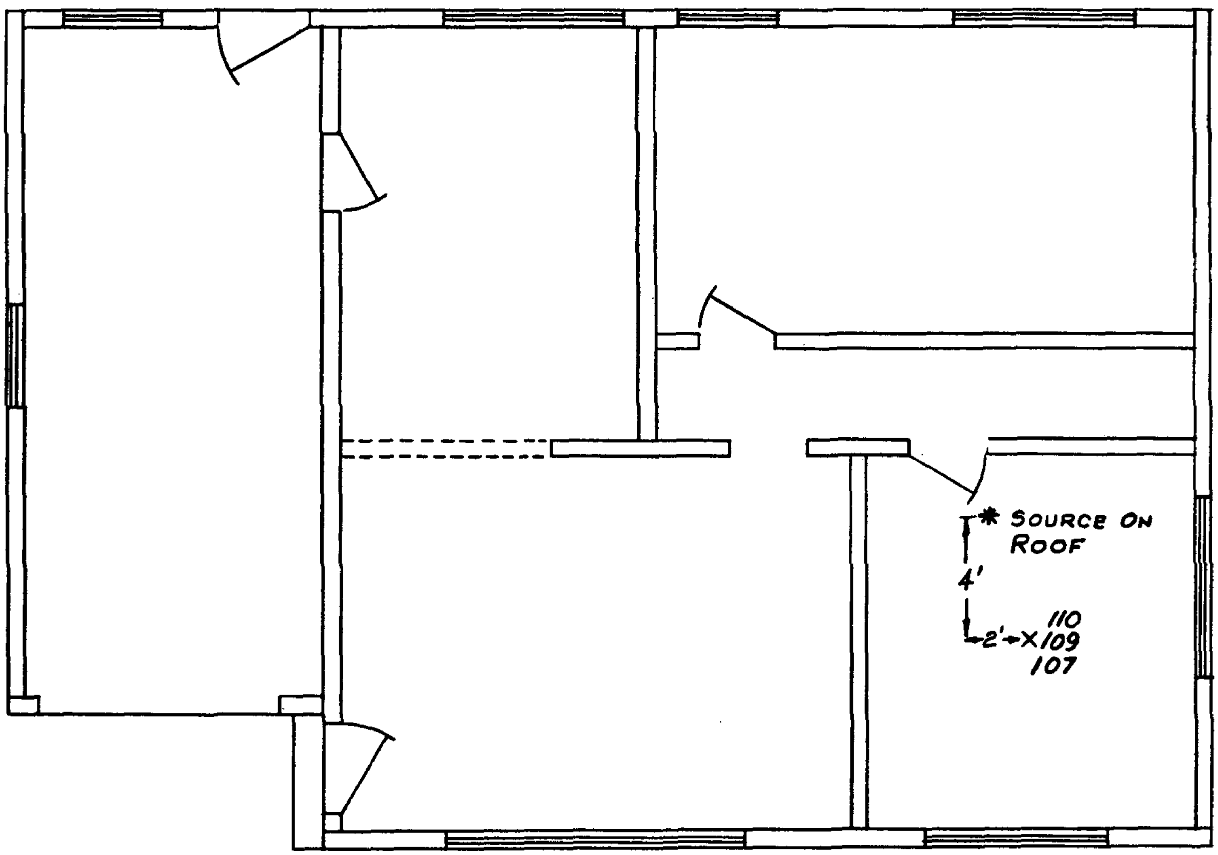

Fig. 3.94—PCC house. reciprocity exposure, 2.1-curie Co^{60} source, dose rates at center of northwest bearoom 3 ft above floor.

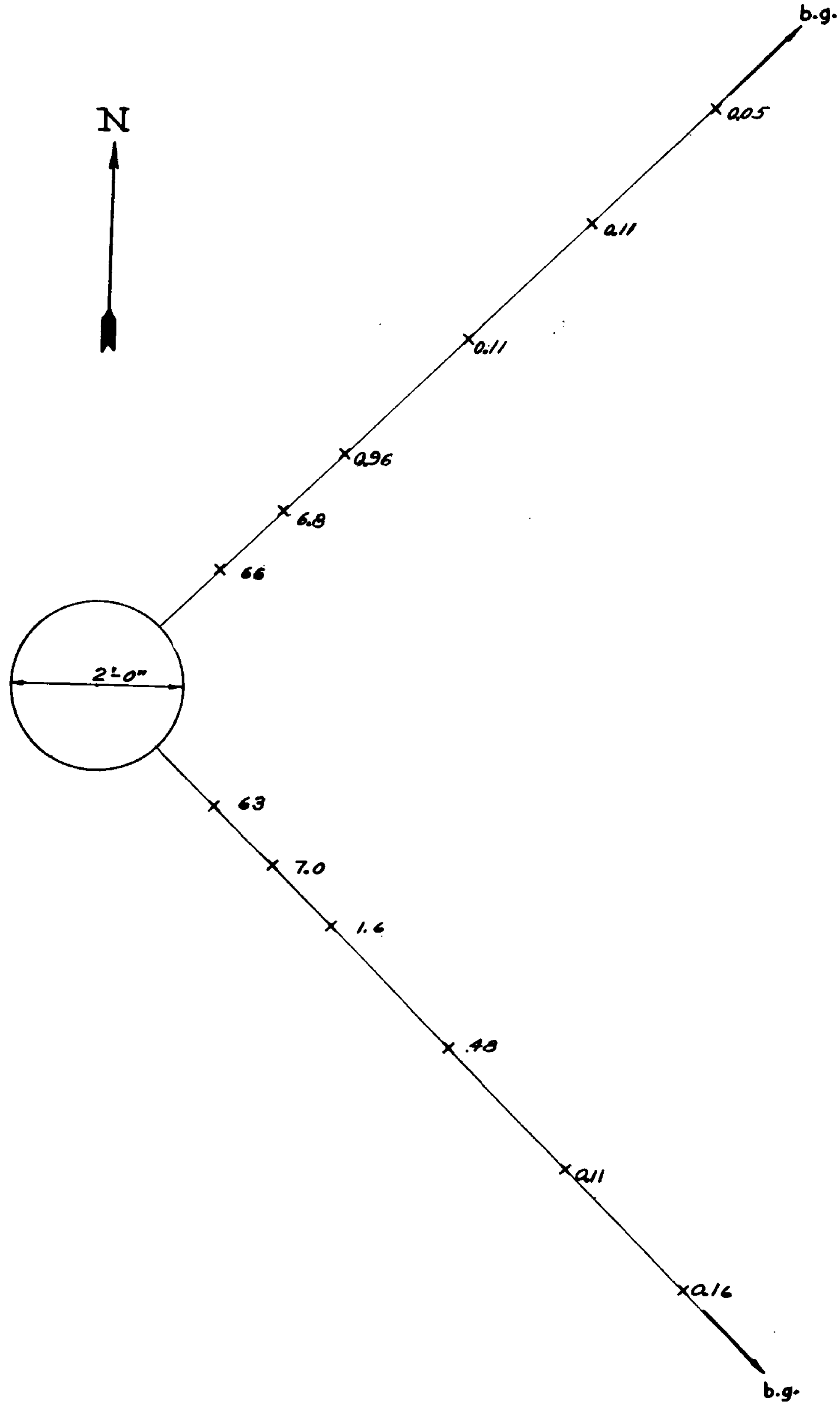

Fig. 3.95—Skyshine exposure, 2.1-curie Co^{60} source 3 ft below ground level.

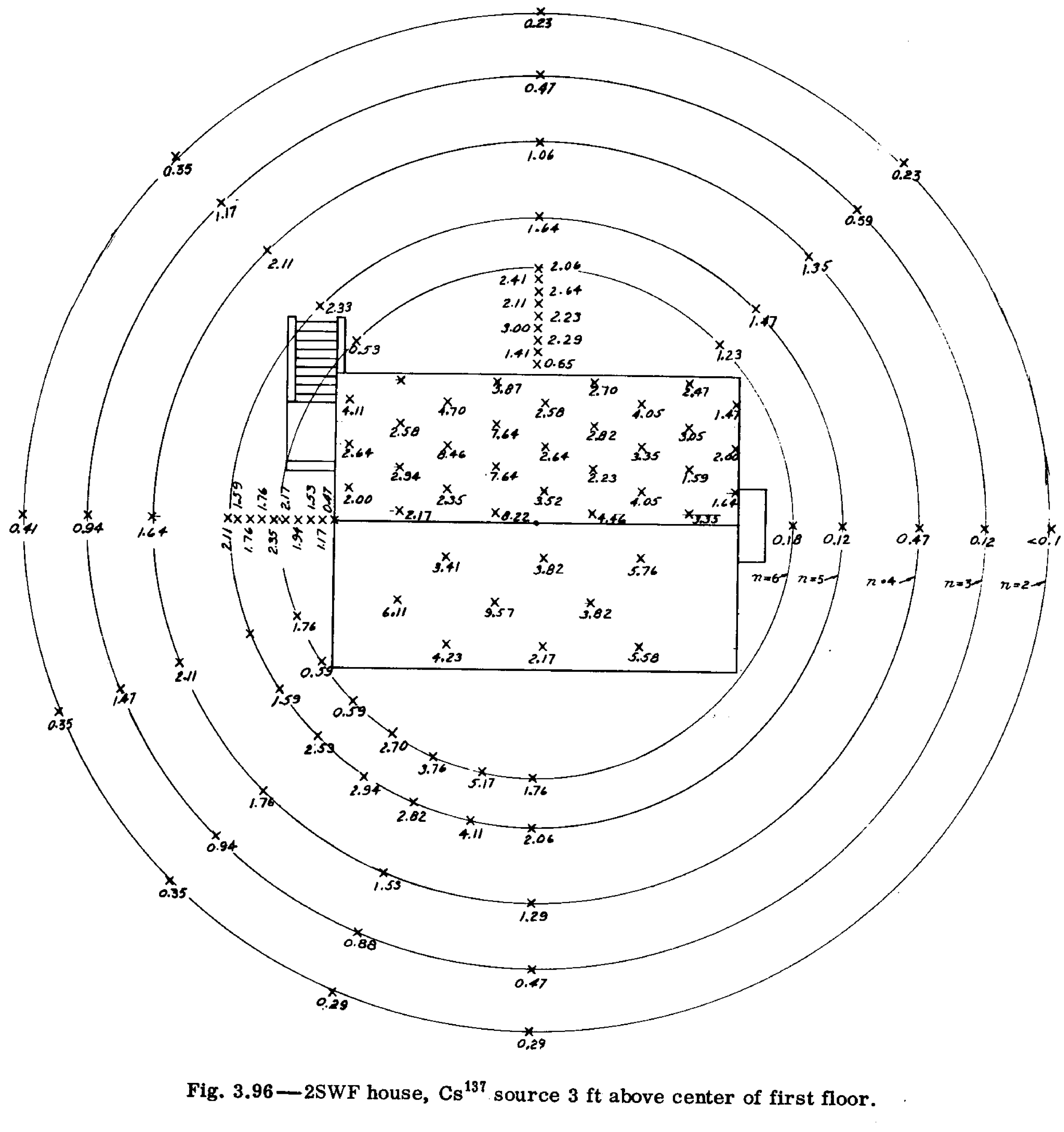

Fig. 3.96—2SWF house, Cs^{137} source 3 ft above center of first floor.

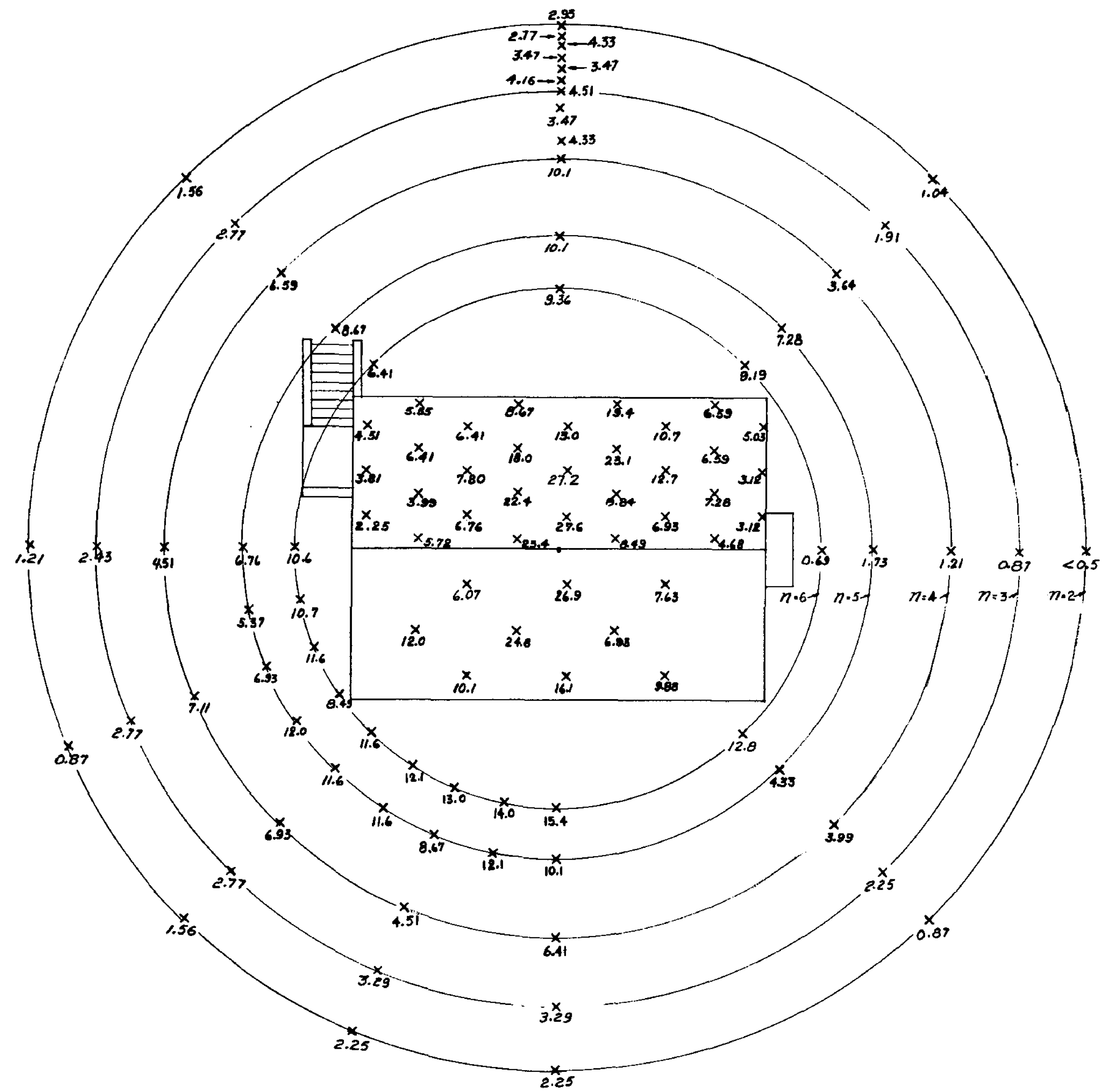

Fig. 3.97 — 2SWF house, Cs^{137} source 3 ft above center of second floor. (All values on circles n = 2 to n = 6 should be multiplied by 0.225.)

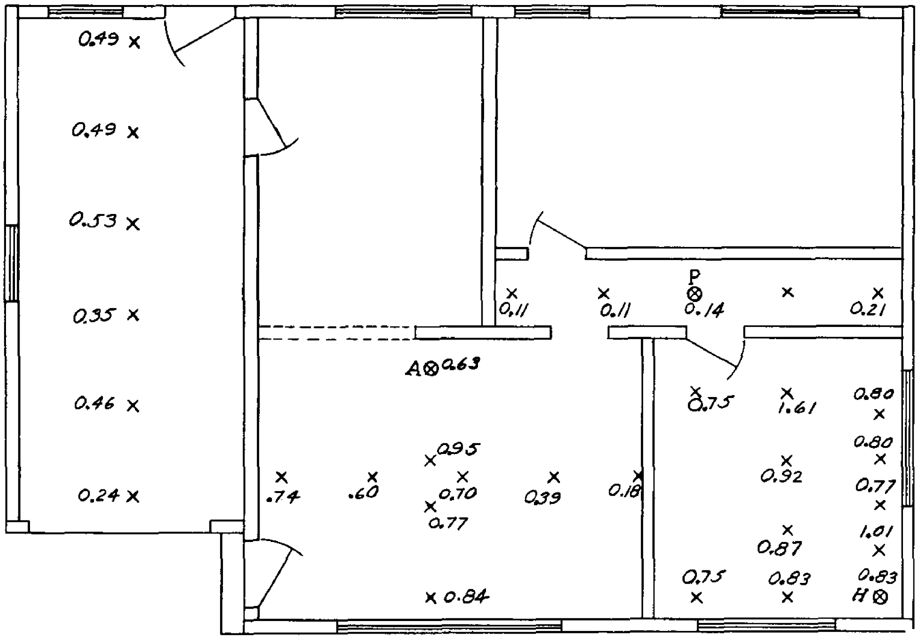

Fig. 3.98—PCC house, 3-ft level, 19 Cs^{137} sources on roof in uniform array.

TABLE 3.47—VERTICAL TRAVERSES FOR THE PCC HOUSE FOR Cs^{137} SOURCES ON THE ROOF

Position	1 ft	3 ft	5 ft	7 ft
A	0.18	0.63	1.05	0.53
H	0.67	0.83	1.54	3.05
P	0.07	0.14	0.18	0.11

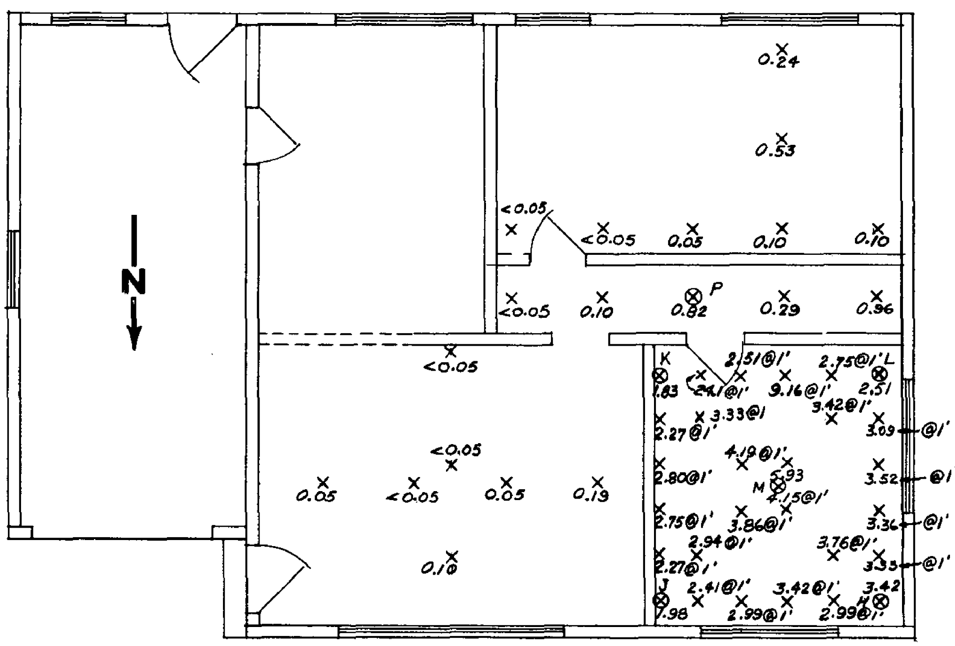

Fig. 3.99—PCC house, 3-ft level, Cs^{137} sources distributed over northwest bedroom. (All values should be multiplied by 0.08.)

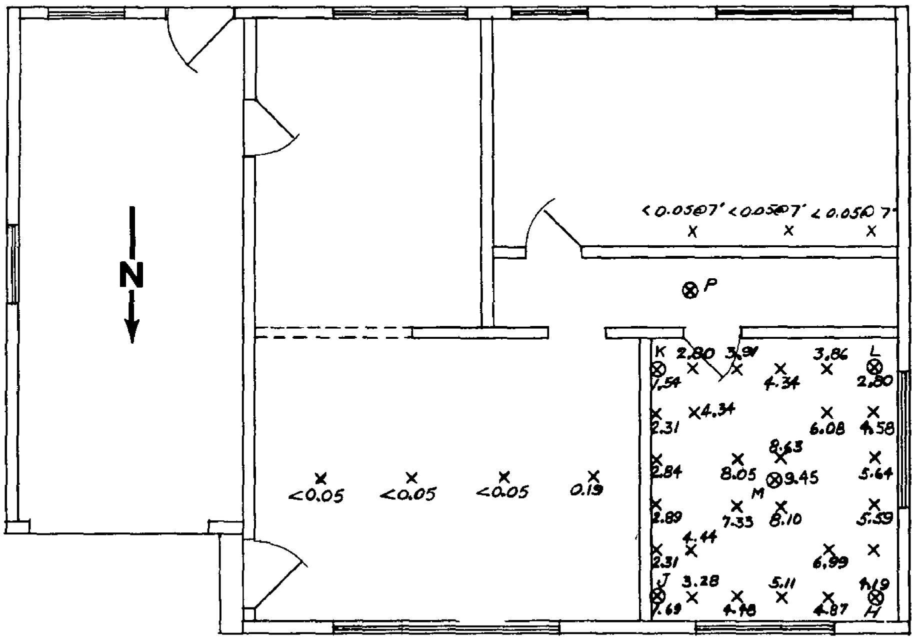

Fig. 3.100—PCC house, 5-ft level, Cs^{137} sources distributed over northwest bedroom. (All values should be multiplied by 0.08.)

TABLE 3.48—VERTICAL TRAVERSES FOR THE PCC HOUSE FOR Cs^{137} SOURCES OVER THE NORTHWEST BEDROOM*

Position	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft
H	2.84		3.42		4.19		4.58	
J	1.93		1.98		1.69		0.58	
K	1.83		1.83		1.54		0.63	
L	2.41		2.51		2.80		2.27	
M	4.34	4.82	5.93	7.23	9.45	9.16	10.6	10.5
P	0.92		0.82				0.29	

*All values should be multiplied by 0.08.

Chapter 4

PRELIMINARY ANALYSIS

A complete analysis of the data presented in this report would probably take several months. In view of the interest of many planning groups in experimental shielding information, it was decided to present these data as quickly as possible with only a minimum of analysis and to follow with a more complete analysis after the data have been studied thoroughly. It is expected that the National Bureau of Standards will be primarily responsible for this analysis. A preliminary analysis is given to indicate the agreement between experiment and theory and to illustrate the type of information which can be obtained from these data.

4.1 FINITE RECTANGULAR SOURCE

Measurements made on the phantom structure can be compared directly with calculated values. When the dose rate is calculated from a uniformly distributed rectangular source, it is convenient to replace the rectangle with a circle of equal area. The effective radius, ρ_0, of the equivalent circular source is then defined by

$$\pi\rho_0^2 = lw$$

where l and w are the length and width of the rectangular source. Neglecting attenuation and scattering, the dose rate at a height h above the center of the circle is given by

$$R = A \int_0^{\rho_0} \frac{\rho \, d\rho}{\rho^2 + h^2} = A \int_1^{\cos\theta_0} \frac{d(\cos\theta)}{\cos\theta} = - A' \log \cos\theta_0$$

where θ is the polar angle between the vertical and a line to the annulus of radius ρ (Fig. 4.1) and

$$\tan\theta_0 = \frac{\rho_0}{h}$$

The constant A′ is determined from

$$A' = 2\pi S_0 C \ln 10$$

where S_0 is the source strength per unit area and C is the dose rate at unit distance from a source of unit strength. For a source strength of 1 millicurie/sq ft and a conversion factor of 14.4 mr/hr at 1 ft from a 1-millicurie point Co^{60} source, A′ = 208.

In Fig. 4.2, the experimental dose rates listed in Table 4.1 are compared with the function

$$R = -208 \log \cos\theta$$

The experimental values are slightly lower than the calculated values. Since dose-rate build-up due to scattered radiation was neglected in the calculations, the experimental results should actually lie somewhat higher than the calculated line.

A possible reason for low readings on the dosimeters at the 3- and 5-ft levels is that they were placed at the intersection of several aluminum tubes fastened with solid aluminum clamps.

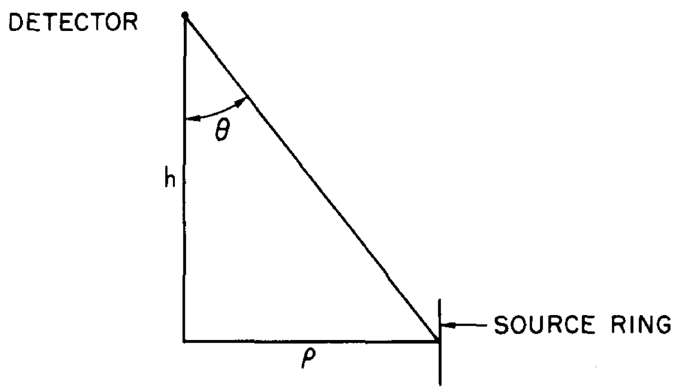

Fig. 4.1—Relation of variables ρ, θ, and h.

Thus a rather large portion of the solid angle seen by the detector contained attenuating material. A more accurate value for these two positions can be estimated by examining the horizontal dose-rate distribution along the diagonal. Figure 4.3 shows that the central points are lower than is consistent with the points away from the center. The two circles in Fig. 4.2 represent the values at these two heights extrapolated from two curves in Fig. 4.3. They are considered to be more reliable than the uncorrected values. A more detailed analysis of these results will be included in the later report.

The experimental results show that dose rates above rectangular sources can be calculated with an accuracy of better than 10 per cent by replacing them with circles of equal areas. This method is expected to yield results good to 10 per cent for rectangles of other dimensions, provided the ratio of w/l satisfies

$$0.8 \lesssim \frac{w}{l} < 1$$

For calculations of dose rates above rectangular sources where $w/l \lesssim 0.8$ and where the detector is not over the center of the rectangle, see Ref. 1.

4.2 CALCULATION OF INTEGRATED VALUES FROM GROUND SOURCES

The experimental values presented in this report give the dose rates from concentric rings of sources. The normalization is such that the linear source density along the circumference is 2 millicuries/ft.

The results must be integrated over the radial variable in order to obtain the dose rate from a plane source. In converting the results for discrete rings to equivalent results for a continuous source distribution, the number of rings per unit radial length will be determined by the desired source strength per unit area. The integrated dose rate from all sources beyond a radius ρ_0 is given by

$$R_0 = \int_{\rho_0}^{\infty} R_r \left(\frac{\text{mr/hr}}{\text{ring}}\right) \times k \left(\frac{\text{number of rings}}{\text{unit radial length}}\right) \times d\rho$$

If ρ is expressed in feet, then the number, k, of rings per unit radial length required to produce a uniform plane source distribution of 1 millicurie/sq ft is $k = \frac{1}{2}$ ring per unit radial length since the linear source density along the circumference of a ring is 2 millicuries/ft. Therefore

$$R_0 = \int_{\rho_0}^{\infty} \frac{R_r}{2}\, d\rho$$

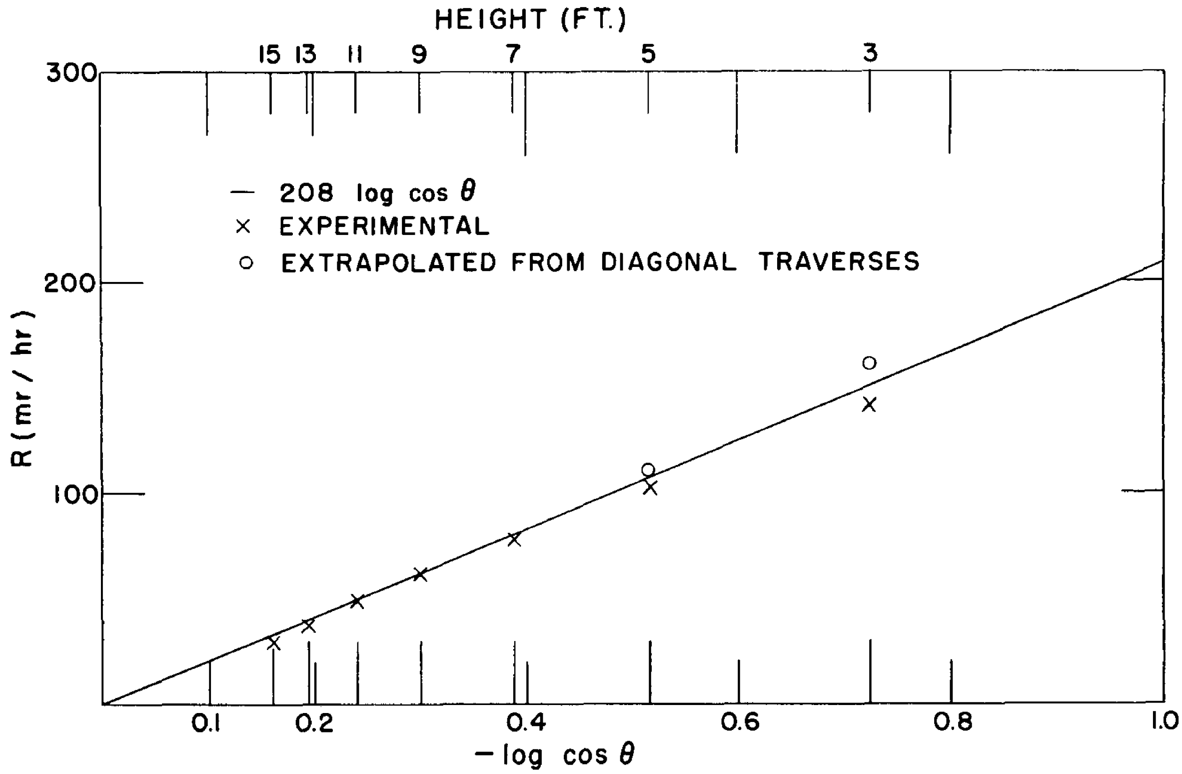

Fig. 4.2—Dose rate as a function of height above the plane.

TABLE 4.1—A′ LOG COS θ AS A FUNCTION OF HEIGHT (h)

Height (h), ft	Tan θ	θ	Log cos θ	A′ log cos θ
1	15.6	86° 20′	1.104	230
3	5.20	79° 7′	0.724	151
5	3.12	72°14′	0.516	107
7	2.23	65° 51′	0.388	81
9	1.73	59° 59′	0.301	63
11	1.42	54° 51′	0.240	50
13	1.20	50° 12′	0.194	40
15	1.040	46° 8′	0.159	33
17	0.918	42° 34′	0.133	28
19	0.821	39° 24′	0.112	23
21	0.743	36° 37′	0.095	20
24	0.650	33° 2′	0.077	16 (basement)

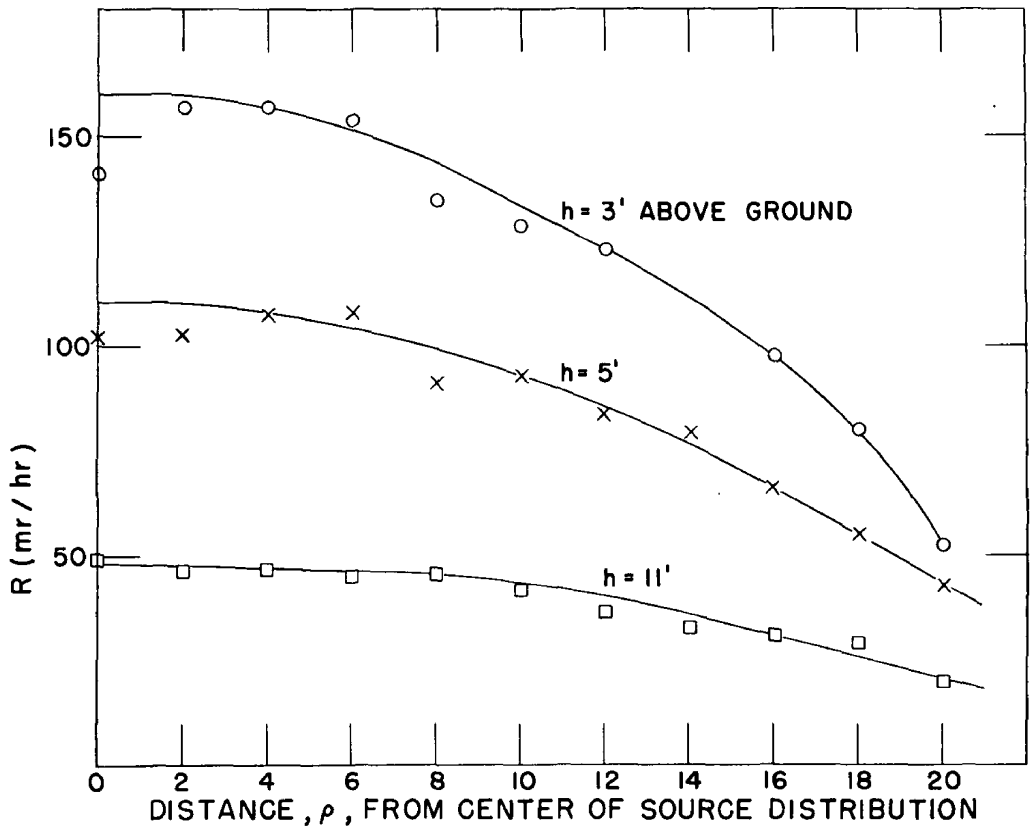

Fig. 4.3—Dose rate vs. distance from center for a rectangular source distribution.

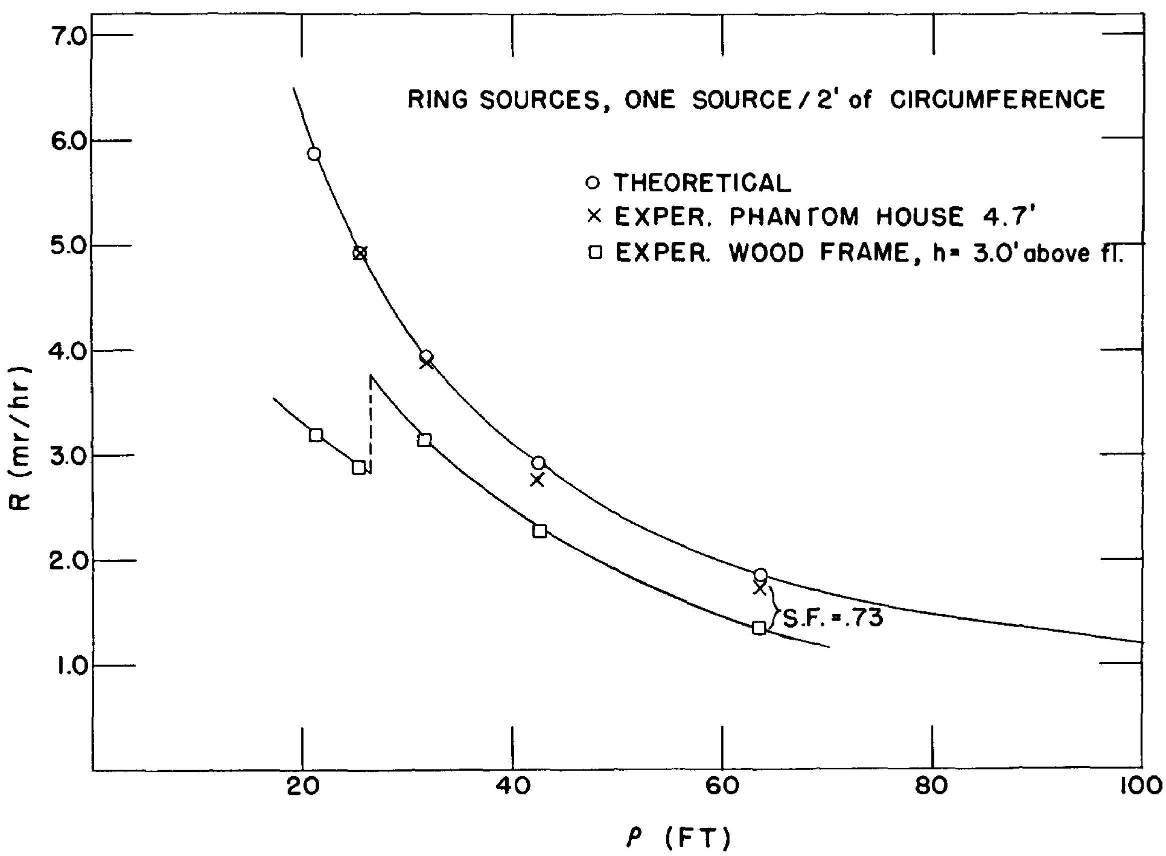

Fig. 4.4—Dose rate vs. distance ρ for phantom and 2SWF houses, ring sources.

and all dose rates must be divided by 2 to obtain the dose rate per unit radial foot of source distribution. Since this factor is introduced only in the integration process, it was not included in the normalization of the experimental results.

The dose rate 4.7 ft above the ground, at the center of the phantom house, is plotted as a function of the radius of the ring sources in Fig. 4.4. It should be noted that the experimental values have all been reduced by a factor of 2 in accordance with the discussion in the preceding paragraph. Although a more detailed analytical treatment of these data is planned, a preliminary analysis can be made by considering only unscattered radiation in the case of the phantom structure. The theoretical expression for the dose rate at a distance h above a point P on a plane from an annular source about P of radius ρ and thickness $d\rho$ is

$$R\, d\rho = \frac{2\pi C S_0\, e^{-\mu(\rho^2 + h^2)^{1/2}}\, \rho\, d\rho}{\rho^2 + h^2}$$

where C is the dose rate at unit distance from a source of unit strength, S_0 is the source strength per unit area, and μ is the linear absorption coefficient for air. It can be seen that the experimental values for the phantom house agree very closely with the theoretical curve for direct radiation above. The scattered radiation is expected to contribute from 5 to 10 per cent additional dose rate. The experimental points are therefore lower than the theoretical points but are within the estimated error of 10 per cent owing to absolute calibration.

The experimental values agree well enough with the calculated curve to justify extrapolating it in order to obtain the integrated dose rate for an infinite plane. Then

$$R_\infty = 2\pi C S_0 \int_0^\infty \frac{e^{-\mu(\rho^2 + h^2)^{1/2}}\, \rho\, d\rho}{\rho^2 + h^2} = 2\pi C S_0 \int_h^\infty \frac{e^{-\mu r}\, r\, dr}{r^2} = -2\pi C S_0 E_i(-\mu h)$$

where $-E_i(-x)$ is the exponential integral function. The value obtained then for unit source density is

$$R_\infty = 2\pi \times 14.4 \times E_i(0.002 \times 4.7) = 375\ \frac{\text{mr/hr}}{\text{millicuries/sq ft}}\ \text{(unscattered radiation only)}$$

This value is undoubtedly low since radiation scattering was neglected in the extrapolation. Unfortunately, evaluation of the scattered component can be made only at source-detector distances that were too great to allow measurements in this experiment. NBS calculations of build-up factors at the ground-air interface indicate that this value should be about 20 per cent higher. The integrated dose rate from the ground, excluding a finite rectangle equal in area to that occupied by the wood frame house, can be obtained by subtracting the corrected experimental dose rate for the rectangular source (Fig. 4.3) from the infinite plane dose. This calculation yields (375 – 125) = 250 mr/hr.

4.3 CALCULATION OF SHIELDING FACTORS

The shielding factor afforded by any structure against radiation from a uniformly contaminated plane can be defined as the ratio of the dose rate in the open at a given height above the plane to the dose rate at the same height inside the structure. It is convenient to separate two factors that contribute to the over-all shielding. The first factor is the redistribution of source material due to the presence of the structure. In the simple case of a rectangular building with a flat roof, this consists in removing a rectangular area of source distribution from ground level and replacing it by a similar distribution at roof level. The second factor is the attenuation due to structural materials and contents of the building.

The phantom house was constructed in order to separate these two effects experimentally. This permitted measurement of the dose-rate distribution from a finite rectangular source and from concentric source rings. The first measurement can be used to obtain the dose rate from a rectangular roof of infinitesimally thin material. Although the source distribution was actually at ground level rather than at the height of a typical roof, the difference in backscattering from the ground for the two cases is expected to introduce an error of less than 10 per cent in dose rate. The results for ring sources by suitable extrapolation and integration can be used to obtain the dose rate from a contaminated area surrounding a house with infinitesimally thin walls. In addition, the dose rate above an infinite plane was obtained by integrating over all radii.

Partial shielding factors, due only to attenuation, for roof sources and ground sources around actual structures can be obtained in the following manner. The shielding factor from sources distributed on the roof of a building is given by the ratio of dose rate above the finite rectangular source (phantom structure) to that at an equal distance below the roof of the building. Shielding factors for the ring sources used in this experiment can be obtained simply as the ratio of the dose rate in the phantom structure to that at the corresponding position in the actual building. Shielding factors for a plane-distributed source around a structure can be estimated by studying the shielding factor as a function of the source radius and calculating an integrated shielding factor. The type of calculation will depend on the detector position being examined. An example is given in Sec. 4.4.

The relative contributions from the roof and ground contamination can be obtained by comparing the measured dose rate from the roof with the integrated value obtained for ground sources. Finally, the total shielding factor can be obtained by comparing the sum of the dose rates from roof and ground sources with the dose rate from the infinite plane source.

4.4 EXAMPLE

To illustrate this procedure, we shall study the shielding factor 3 ft above the first floor (4.7 ft above ground) at the center of the two-story wood frame house. Since this house was studied in the most detail, it is the most amenable to this procedure. In Fig. 4.4, the dose rate at 3 ft above the first floor is plotted together with the dose rate at the center of the phantom house at the same distance above ground. For a distributed source on the ground around this house, we combine the results of exposure 6 with an integrated dose rate obtained from Fig. 4.4. Exposure 6 gives the dose rate from sources distributed on the four ground segments lying between the walls of the house and a circle of 20 ft radius. The latter rate, obtained from Fig. 3.5, is 7.6 mr/hr. The shielding factor for ring sources has two distinct values. For radii $\gtrsim$30 ft, only the walls of the first floor lie between the sources and the detector. For radii $\lesssim$30 ft, the first-floor structure and the concrete foundation also lie between the sources and the detector. Assuming that the transmission due to the walls alone is 0.8 (see Fig. 4.4) and that due to the walls plus the floor is 0.6, the integrated dose rate was calculated from

$$R = R_\infty \frac{0.8E_i(\mu r_1) + 0.6\,[E_i(\mu r_0) - E_i(\mu r_1)]}{E_i(\mu h)}$$

where

$$r_0^2 = (20)^2 + (4.7)^2$$

and

$$r_1^2 = (30)^2 + (4.7)^2$$

The integrated dose rate from $\rho = 20$ ft to $\rho = \infty$, using the curve in Fig. 4.4, is 192 mr/hr. The sum of this result and that of exposure 6 yields 200 mr/hr as the dose rate from the ground.

The dose rate at h feet below a finite plane source representing the roof is obtained from Table 4.1. The detector position 3 ft above the first floor in the two-story wood frame house corresponds to a distance of 17.0 ft below the mean level of the roof, or a dose rate of 25 mr/hr. This is the dose rate in the absence of any attenuating material between the source and the detector.

For a distributed source on the roof of the two-story frame house, the dose rate 3 ft above the first floor, center, from Fig. 3.45, is 17.2 mr/hr. The transmission of the intervening roof and ceilings is therefore 17.2/25 = 0.69. At this detector position the ground radiation contributes about 10 times as much to the dose rate as does the roof, the total dose being 219 mr/hr. Comparing this with the infinite plane value yields a total shielding factor of 1.7.

TABLE 4.2—EXPERIMENTAL RADIATION REDUCTION FACTORS* DUE TO MODIFICATIONS IN TEST STRUCTURES

Modification	Reduction factor	Remarks
Debris shelter in basement with 8-in. concrete walls and ceiling	0.050 ± 0.025	Large spread due to poor statistics of low readings in basement; factor applies to radiation sources on roof
Corner shelter with 7-in. concrete cover; detector directly beneath shelter	0.20 (minimum) ± 0.09	Protection decreases away from corner; large spread due to poor statistics of low readings in basement; factor applies to radiation sources on roof
Table covered with 7 in. of concrete; detector directly beneath table	0.20 ± 0.08	Large spread due to poor statistics of low readings in basement; factor applies to radiation sources on roof
Stair well with 8-in. concrete walls and no ceiling; detector height = 3 ft	0.70 ± 0.07	Very sensitive to height
Heavy kitchen furniture between source and detector (see Fig. 2.28)	0.75 (minimum) ± 0.10	Same factor for both roof and ground radiation
Bathroom fixtures between source and detector (see Fig. 2.29)	0.89 ± 0.03	Shielding would be somewhat more effective if tub contained water; same factor for both roof and ground radiation
Living-room furniture	1.0	No measurable reduction
Walled-up picture window in PCC; detector height = 3 ft	0.4 → 0.7	Extreme values from 1 ft in front of window → other side of room
Low wall in rambler; detector height lower than top of wall	0.68 ± 0.05	Wall around entire house would reduce factor to about 0.5
Sandbagged windows in basement	~0.75 ± 0.25	Factor may be as low as 0.25 but only for sources within a few feet from house and with detector in front of window

*Reduction factor is defined as the ratio of dose rate at a given point with the modification to that without the modification.

4.5 GENERAL CONCLUSIONS

In many cases conclusions to be drawn from the data of this experiment will depend on a more detailed analysis. There are certain general conclusions, however, which can be reached either from a cursory examination of the data or from a preliminary analysis of the type illustrated in Sec. 4.4. It is worthwhile to list these results.

1. As expected, the best-shielded region in a residential structure is in the basement. The two-story wood frame house effectively has two half-basements owing to the concrete walls in the center. The dose rate (from both roof and ground sources) at a point 3 ft above the center of either half-basement floor is reduced by a factor of 30. Here the reference dose rate is that at 3 ft above an infinite contaminated plane.

2. In a two-story house with light frame construction, the radiation sources on the ground contribute the major part of the dose rate at points on the first and second floors. The relative dose-rate contributions from ground and roof sources at various locations are as follows:

Detector position	Ground sources : roof sources
3 ft above center of second floor	4:1
3 ft above center of first floor	10:1
3 ft above center of half-basement	~1:1

Although the basement offers much greater shielding against ground radiation sources than against roof sources, the ground source is much larger in area, with the result that the net contributions to the dose rate are about equal.

3. In a house with light-frame construction, the attenuation of ground radiation by certain structures is sufficient to cast radiation "shadows." Next to a brick chimney, where the detector is hidden from half the ground sources, the dose rate was found to be reduced by a factor of 2. It was found that wooden floors of the type found in the two-story wood frame house reduce dose rates by a factor of 2 for slant radiation from the ground. Another factor of 2 is gained if the detector is in the shadow of the concrete foundation.

4. For points in the two-story wood frame house which are shielded from the ground radiation by wooden walls alone, the dose-rate reduction factor is only about 1.25.

5. Measurements with a point source in the two-story wood frame house and detectors outside show that for equal source-detector distances the dose rates may vary by a factor of 4. This variation is due to the inhomogeneous nature of the walls and floors.

6. Measurements on the precast concrete house show that shielding factors for a ground ring source of 42.5 ft radius vary from 1.6 to 12.0, depending on the average number of walls between the detector and the ring source.

7. Dose rates on the first floor of the two-story brick house from ground sources are smaller by a factor of 4 than those for comparable positions in the two-story wood frame house. This applies only to points that receive no direct radiation through windows.

8. Dose rates in the wood rambler from roof sources are about the same as those on the second floor of the two-story wood frame house (attenuation by roof about 25 per cent). Dose rates from ground sources are somewhat lower (10 to 20 per cent) than those on the first floor of the two-story wood frame house because of the plastered walls in the rambler.

9. Although the wood frame structures in this test offer little radiation protection except in basements, modifications such as those listed in Table 4.2 will increase shielding capabilities. The total shielding factor in a corner of the basement of a brick home under a shielded table with sandbags covering the external openings is of the order of 1/1000 as compared to 3 ft above an unshielded plane.

REFERENCE

1. M. J. Berger and J. C. Lamkin, Sample Calculations of Gamma-ray Penetration into Shelters: Contributions of Skyshine and Roof Contamination, Report NBS-2827, February 1958.

Appendix A

FILM BADGES

On four of the exposures some bare film packets of Eastman Kodak personnel monitoring film, type 2, were placed on or very near the PIC's. No precautions were observed to minimize heat fogging. The film exposures were made in this simplest and crudest manner only as a check of the reproducibility and range of usefulness under field conditions. In some cases three films were placed at the same point, with the planes of the film mutually perpendicular. The films were processed and read by the Film Badge Department of the University of California, Berkeley. Film densities were corrected to dosage and normalized by calibration of the film batch with the 8.40-millicurie Co^{60} reference standard. A comparison of the dose rates measured with film to those measured with the PIC's at corresponding positions is given in Table A.1. Each set of data is similar to that given; there was no detectable difference in the ratios of film to PIC from house to house. The film values were relatively consistent, internally, and generally indicated a higher reading than the PIC's.

TABLE A.1—COMPARISON OF FILM AND PIC READINGS NORMALIZED TO THE SAME CALIBRATION

Film, mr	PIC (corrected), mr	Film, mr	PIC (corrected), mr	Film, mr	PIC (corrected), mr
235	167	121	69	159	95
279	214	93	40	203	131
324	242	86	61	228	161
80	52	228	178	203	138
108	63	71	33	140	72
194	138	70	29	169	72
206	150	92	49	64	6
186	115	78	40	71	17
145	115	70	32	59	2
129	98	92	46	135	242
107	83	108	57	214	126